Evaluation Tools to Support ITS Planning Process: Development of a Sketch Planning Tool in FSUTMS/Cube Environment

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Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

Metric Conversion Chart

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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16. Abstract

Intelligent Transportation Systems (ITS) planning requires the use of tools to assess the performance of ITS deployment alternatives relative to each other and to other types of transportation system improvement alternatives. This research project investigates the development of tools and procedures to perform sketch-planning evaluation of the costs and benefits of ITS alternatives within the Florida Standard Urban Transportation Model Structure (FSUTMS) modeling environment.

The script language of Cube, the modeling engine of FSUTMS was used to implement the evaluation tool procedures. Developing an ITS evaluation capability as part of the FSUTMS will allow a more powerful, user friendly, and consistent evaluation of ITS deployment alternatives. The implemented procedures allow the evaluation of amp metering, incident management systems, highway advisory radio (HAR) and dynamic message signs (DMS), advanced travel information systems, managed lanes, signal control, transit vehicle signal priority, emergency vehicle signal priority, monitoring and management of fixed route transit, transit information systems, transit security systems, transit electronic payment systems, smart work zones, road weather information systems (RWIS). Depending on the types of the evaluated ITS deployments, the tool can produce ITS impacts on various performance measures including vehicle miles of travel (VMT), vehicle hours of travel (VHT), average speed, number of accidents, fuel Consumption, monetary benefits to users and/or agency, and emission.

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Executive Summary

The Florida Standard Urban Transportation Model Structure (FSUTMS) represents a formal set of modeling steps, procedures, software, file formats, and guidelines established by the Florida Department of Transportation (FDOT) for use in travel demand forecasting throughout the State of Florida. The planning of Intelligent Transportation Systems (ITS) requires the use of tools to assess the performance of ITS deployment alternatives relative to each other and to other types of transportation system improvement alternatives. Existing travel demand models do not have the ability to assess the impacts of ITS, although ITS sketch planning tools have been developed for this purpose. These tools use the data produced by demand forecasting models as inputs. The current FSUTMS software environment has powerful data handling and modeling capabilities that allow the implementation of advanced evaluations of ITS deployments as part of this environment. This implementation of ITS evaluation capabilities will allow powerful, user friendly, flexible, and consistent evaluations of ITS deployment alternatives in Florida.

The goal of this project is to assess and develop tools and procedures to perform sketch planning evaluation of the costs and benefits of ITS alternatives within the FSUTMS/Cube software environment. The specific objectives of the project are:

- To assess the methods and procedures used in previous studies and existing sketch planning tools to evaluate ITS deployment
- To identify methods to evaluate ITS deployment alternatives
- To identify modules to estimate travel time/delay, fuel consumption, emission, and crashes as part of the developed tool
- To identify default benefit, cost, and dollar value parameters for use in the developed tool
- To identify processes for implementing the identified procedures and methods in regional FSUTMS models
- To implemented and test the procedures and methods in an FSUTMS modeling environment.

It is possible to evaluate the following types of ITS deployments with the current version of the tool developed in this project:

- Ramp metering
- Incident management systems
- Highway advisory radio (HAR) and dynamic message signs (DMS)
- Advanced travel information systems
- Managed lanes

- Signal control
- Transit vehicle signal priority
- Emergency vehicle signal priority
- Monitoring and management of fixed route transit
- Transit information systems
- Transit security systems
- Transit electronic payment systems
- Smart work zones
- Road weather information systems (RWIS)

This project identified and implemented an evaluation method for each of the above evaluated ITS deployment components. These methods require three types of parameters: 1) ITS impact factors, 2) cost parameters, and 3) benefit dollar values. The default values for these parameters were selected based on a review and assessment of the information available on the subject.

Depending on the types of the evaluated ITS deployments, the tool can produce various performance measures including:

- Vehicle miles of travel (VMT);
- Vehicle hours of travel (VHT);
- Average speed;
- Number of accidents
    - Fatality
    - Injury
    - Property damage only
- Fuel Consumption (gallons)
- Monetary benefits to users and/or agency, as appropriate
- Emission (gm)
    - Hydrocarbon
    - Carbon monoxide
    - Oxides of Nitrogen

Sketch planning tools require base modules to estimate the above performance measures based on network geometry and traffic operation parameters. Some of the required modules are already available in the FSUTMS. Other modules required to calculate the performance measures are not currently available in the FSUTMS and had to be implemented in this study. These additional modules include those required to estimate emissions, fuel consumption, and safety.

Because of the differences in the structures and variables of FSUTMS implementations in various Florida regions, it is anticipated that an additional effort will be required to incorporate the developed tool in the FSUTMS regional models.

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1 Introduction

1.1 Background

Intelligent Transportation Systems (ITS) planning requires the use of tools to assess the performance of ITS deployment alternatives relative to each other and to other types of transportation system improvement alternatives. A number of sketch planning tools have been developed to support the evaluation of ITS alternatives based on the utility-based and/or the economical-based approaches.[1] These tools range in details from simple spreadsheets with simplified assumptions like the SCReening Analysis for ITS (SCRITS) tool,[2] to more sophisticated tools like the ITS Deployment Analysis System (IDAS)[3] and the ITS Options Analysis Model (ITSAOM).[4]

The Florida Standard Urban Transportation Model Structure (FSUTMS) represents a formal set of modeling steps, procedures, software, file formats, and guidelines established by the Florida Department of Transportation (FDOT) for use in travel demand forecasting throughout the State of Florida. The FSUTMS models are calibrated to match observed traffic volumes for a given point in time. Once this is accomplished, the models may then be used to forecast future traffic demands and performance.

The Florida Department of Transportation (FDOT) led an effort to develop an approach to interface the FSUTMS and IDAS programs.[5] An additional FDOT effort[6,7] customized the IDAS benefit and cost parameters and databases to better reflect the Florida benefit/cost values.

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[1] Hadi, M.A., D. Quigley, P. Sinha, and L. Hsia, "Using IDAS as Part of the Ranking Process of ITS Deployment Alternatives," Presented at the 12th World Congress on ITS, San Francisco CA, November 2005.

[2] "User's Manual for SCRITS, Screening Analysis for ITS," Prepared for Federal Highway Administration Office of Traffic Management and ITS Applications Prepared by Science Applications International Corporation January, 1999.

[3] "ITS Deployment Analysis System (IDAS) User's Manual," Prepared for the Federal Highway Administration by Cambridge Systematics, Oakland, CA, November 2001.

[4] Thill, J.C., and G. Rogova, "The ITS Options Analysis Model Technical Documentation," Produced for the New York DOT by Calspan UB Research Center and University at Buffalo, Buffalo, NY, October 13, 2005.

[5] "FSUTMS /IDAS Interface – Manual Approach," Prepared for FDOT by Cambridge Systematics, Tallahassee, FL, April 2003.

[6] Hadi, M.A., D. Quigley, P. Sinha, and L. Hsia, "Benefit and Cost Parameters for Use in Evaluations by the Intelligent Transportation Systems Deployment Analysis System in Florida," Transportation Research Record, Washington, D.C., January 2005.

[7] Hadi, M.A., D. Quigley, P. Sinha, and A. Krishnamurthy, "Intelligent Transportation Systems Deployment Analysis System Customization," Final Report Prepared for the FDOT by PBSJ, Inc., Tallahassee, FL, October 27, 2005.

The Metropolitan ITS Deployment tracking effort of the Research and Innovative Technology Applications (RITA) of the United State Department of Transportation (USDOT) indicates that of the 108 largest metropolitan areas in the United States, 20 agencies had used IDAS in their evaluation and planning of ITS by the year 2004.

Despite the powerful modeling capabilities of IDAS, a number of issues are associated with its use to evaluate ITS alternatives in Florida. First, IDAS includes internal models that are different from the calibrated regional demand models. This results in inconsistencies in the evaluation and forecasting processes between IDAS and the regional models. Secondly, IDAS was written in the mid 1990s, thus rendering the software's operations and user interface relatively inflexible and out-of-date. Thirdly, the evaluation methodologies and the ITS components included in the IDAS evaluations were established in the 1990s, when the ITS field was just beginning to be deployed. The ITS field has experienced considerable developments and advancements since then. Thus, a re-evaluation of the methodologies and parameters used in sketch planning tools in needed, based on what has been learned in the past 10 years of ITS deployments.

A Northeastern Illinois case study, conducted by the Chicago Area Transportation Study (CATS) to evaluate IDAS capabilities,[8] suggested that ITS evaluations should be incorporated as part of the CATS regional travel demand models. The study stated that this implementation will ensure the consistency of reporting measures, reducing the duplicated effort on converting the network files and demand matrices into the format required by IDAS, and enhanced analysis capabilities.

The advancements in transportation demand forecasting models and the integration of these models with geographic information systems make them attractive environments for the development of ITS evaluation tools. In 2004, the FDOT model task force selected the Cube software environment as the FSUTMS software engine. This software environment has powerful data handling and modeling capabilities that allow the incorporation of advanced evaluations of ITS deployments.

The research effort discussed in this report is to implement ITS evaluation capabilities as part of the FSUTMS framework, which will allow powerful, user friendly, flexible, and consistent evaluations of ITS deployment alternatives in Florida. It is anticipated that this research is the first phase of an effort to develop an integrated ITS evaluation environment. In the future, it is anticipated that other tools such as mesoscopic and microscopic simulation/dynamic traffic assignment models will be integrated as part of the FSUTMS/Cube environment.

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[8] Heither, C. and M. Thomas, 'Testing of IDAS Capabilities Using Northeastern Illinois ITS Deployments," Working paper 03-06, August 2003.

1.2 Objective

The goal of this project is to assess and develop tools and procedures to perform sketch planning evaluation of the costs and benefits of ITS alternatives within the FSUTMS/Cube software environment. The specific objectives of the study are:

- To assess the methods and procedures used in previous studies and existing sketch planning tools to evaluate ITS deployment
- To identify methods to evaluate ITS deployment alternatives
- To identify modules to estimate travel time/delay, fuel consumption, emission, and crashes as part of the developed tool
- To identify default benefit, cost, and dollar value parameters for use in the developed tool
- To identify processes for implementing the identified procedures and methods in regional FSUTMS models
- To implemented and test the procedures and methods in an FSUTMS modeling environment

Figure 1-1 presents an overview of the tasks performed in this study to satisfy the project objectives.

1.3 Document Organization

This document is organized into the following chapters:

- **Chapter 1 – Introduction:** This section presents background information and the document objectives**.**
- **Chapter 2 – Overall Review of ITS Evaluation:** This chapter contains an overall review of the tools and procedures that have been used in evaluating the benefits and costs of ITS as part of the ITS planning process, in addition to a review of topics related to the evaluation.
- **Chapter 3 – Supporting Modules:** Sketch planning tools require base modules to estimate traffic demands and performance measures based on network geometry and traffic operation parameters. Some of the required modules are already available in the FSUTMS. Other modules required to calculate the performance measures are not currently available in the FSUTMS. This chapter includes a review of the required base models.
- **Chapter 4 – Evaluation Parameters:** The ITS sketch planning evaluation requires three types of parameters: 1) the ITS Impact factors, 2) cost parameters, and 3) benefit dollar values. This chapter presents a discussion of these parameters. The selection of cost and dollar value parameters is discussed in this chapter. The selection of default impact factors for individual ITS components is

discussed in the chapters of this documents that discuss the evaluation of these components (Chapters 6 to 16, as discussed below).

- **Chapter 5 – General Requirement and Design:** This chapter details the general requirements of the ITS evaluation tool, developed as part of this project to support the evaluation of ITS for planning purposes. These requirements address the different types of evaluated ITS deployment, evaluated impacts/performance measures, supporting modules, and other general evaluation requirements.
- **Chapters 6 to 16:** Each of these chapters discusses the evaluation of an individual ITS deployment component. A review and assessment of previous evaluation approaches of the ITS component is presented. Then, the requirements of the evaluation of the ITS component is presented followed by the evaluation methodology used in the tool developed in this study. Finally, the implementation of the evaluation methodology in the tool is discussed including the modeling structure, input interface, and output Interface.

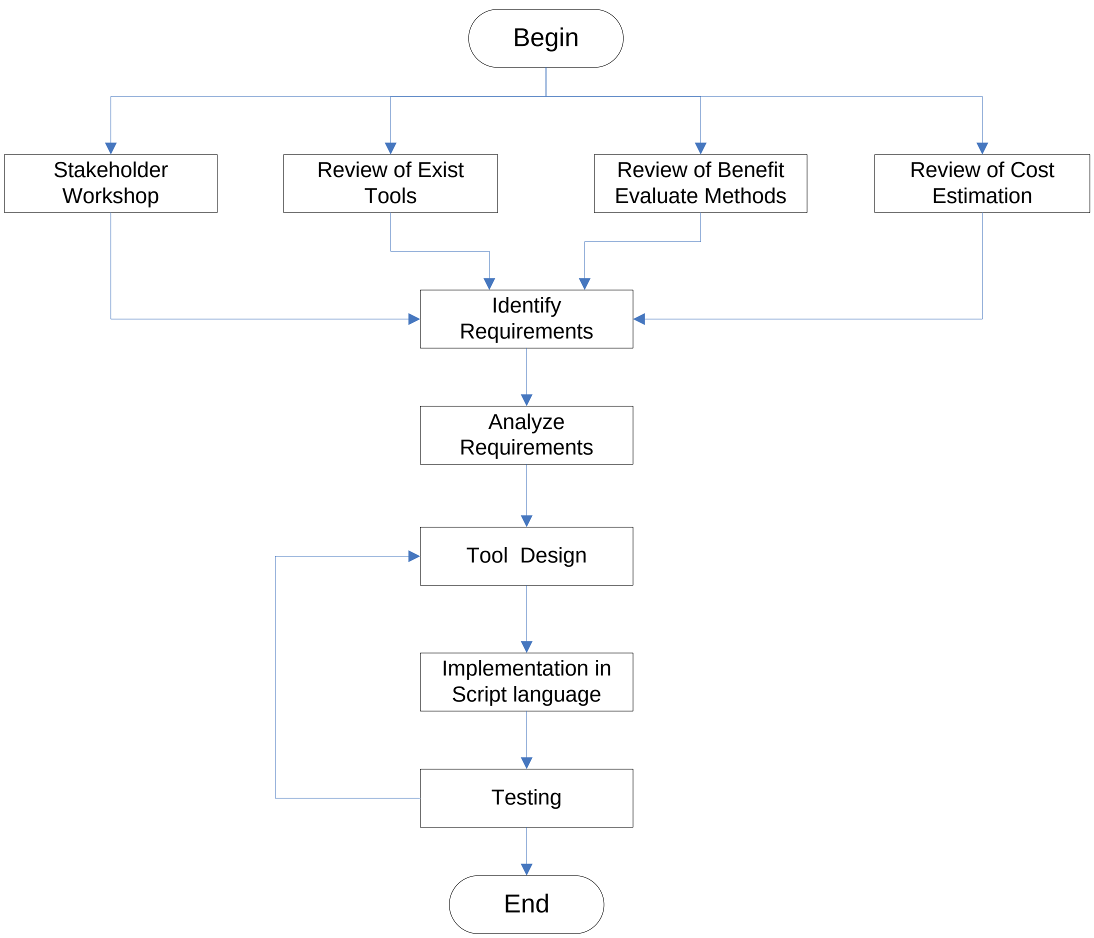

Figure 1-1 Flow Chart of the Development of the ITS Evaluation Tool

2 Overall Review of ITS Evaluation

This chapter contains an overall review of the tools and procedures that have been used in evaluating the benefits and costs of the ITS planning process, in addition to a review of topics related to these evaluations. The review of previous studies related to methods used to evaluate individual ITS components and the supporting modules to calculate various measures of performance have not been incorporated into this chapter, but are detailed in Chapters 6 to 16.

2.1 Goal-Based versus Economical Approaches

The decision to select between ITS deployment alternatives requires the evaluation and ranking of these alternatives relative to each other and possibly to other improvement alternatives. In general, two main approaches have been used in previous studies for the evaluation and ranking of ITS project alternatives:

- The first approach is the utility-based approach, also referred to as the goal-oriented or the performance-based approach: The utility-based approach is based on the calculation of a utility value for each ITS deployment alternative to indicate its ability to meet identified ITS goals and/or performance measures (project ranking criteria).
- The second approach is the economic approach also referred to as the benefit-cost approach. The economical analysis approach compares ITS deployment alternatives based on their benefit to cost ratios or their net present worth (or annualized) benefits.

Previous studies have used either the economic approach or the utility-based approach to decide between ITS deployment alternatives. As stated in Chapter 1, a number of tools have been developed to support the evaluation of ITS alternatives. These tools can be used as part of the ITS evaluation using the utility-based approach and/or the economic approach. However, these tools may not be sufficient to evaluate all the performance measures that need to be considered in the evaluation and ranking ITS deployment alternative. For this reason, the evaluations of some of the quantitative and qualitative measures may need to be done using other processes, in combination with the use of the supporting tools.

The FDOT "Intelligent Transportation Systems Deployment Analysis System Customization" study[9] discussed in Chapter 1 used a ranking procedure that utilizes IDAS to quantify the costs and some of the benefits of ITS deployment alternatives.

[9] Hadi, M.A., D. Quigley, P. Sinha, and A. Krishnamurthy, "Intelligent Transportation Systems Deployment Analysis System Customization," Final Report Prepared for the FDOT by PBSJ, Inc., Tallahassee, FL, October 27, 2005.

Project benefits such as travel-time reductions, environmental improvements, and accident reductions are estimated using IDAS. Other criteria such as supporting evacuation operations, special event traffic, construction activities, and commercial vehicle operations were quantified using off-model calculations. These calculated off-model criteria were assessed without the use of IDAS and used in combination with the measures quantified using IDAS in the overall project ranking process (see Section 2.6 of this report for more details).

The FDOT IDAS customization study mentioned above recommended that the utility-based and the economic approaches should be used in combination with each other. The economic approach results can be used to show how the benefit dollar values compare with the cost dollar values, providing a financial justification for investing in ITS. The utility-based approach can be used to indicate how well the ITS deployment alternatives meet the criteria and weights identified by the project stakeholders.

2.2 Breakeven Analysis

A breakeven analysis was used in an ITS evaluation study in Wisconsin to identify the breakeven points of ITS deployment options.[10] The rationale is that benefit cost analysis cannot be done in a specific location without detailed before and after data on the actual performance of a system. Breakeven analysis provides a method to determine the minimum level of performance necessary for a system to have a level of benefits that equal its costs. Such an analysis can be useful since the results can be assessed to determine how closely the ITS deployment is from an acceptable solution. For example, if a ramp metering system requires a speed increase of 20 miles per hour to break even on a highway that operates at a peak hour speed of 50 mph, it would not be a reasonable alternative since the resulting speed would be in excess of the normal free flow speed on a urban highway. However, if a 5 mph increase were required to break even on a facility with operating speeds of 35 mph, it would be a desirable alternative. A spreadsheet sketch planning tool (SCRITS) was used in the breakeven analysis in the Wisconsin study mentioned above. SCRITS will be described later in this document.

2.3 Existing Sketch Planning Tools

This section consist an overall review of three existing sketch planning tools. Additional reviews of the methods and parameters used in these tools are presented in Chapters 4 to 16 of this study.

[10] Zhong-Ren P. and E. Beimborn, "A Breakeven Analysis for Statewide ITS Project Identification and Assessment," Proceedings of the Transportation Research Board (TRB) annual meeting, Washington, D.C., January 2001.

2.3.1 IDAS

The Intelligent Transportation Systems (ITS) Deployment Analysis System (IDAS)[11] is an ITS sketch planning analysis tool that can be used to estimate the impacts and costs resulting from the deployment of various ITS components. IDAS assesses changes in several performance measures, such as travel time/speed, travel time reliability, fuel costs, operating costs, accidents, emissions, and noise. IDAS also provides benefit to cost comparisons of ITS improvements individually and in combinations.

IDAS can assess the impacts and costs of 12 different categories of ITS deployments. These deployments include: arterial traffic management systems (ATMS), freeway traffic management systems (FTMS), advanced public transit systems (APTS), incident management systems (IMS), electronic payment collection, rail road grade crossings, emergency management services, regional multimodal traveler information systems, commercial vehicle operations (CVO), advanced vehicle control and safety systems, supporting deployments, and generic deployments.

The IDAS software includes default values for the inputs required to calculate the costs and benefits of ITS deployments. These defaults are based on the analysis of the data presented in the USDOT *ITS Benefits* and *ITS Unit Costs Databases*. The default benefits are also based on an extensive review of literature performed by the IDAS developers during the initial development stages of the software. IDAS also allows users to assign weights to ITS project performance measures to determine the overall benefit valuation of the project.

2.3.2 ITSOAM

The ITS Options Analysis Model (ITSOAM)[12] is an intelligent transportation system sketch planning tool developed for the New York State Department of Transportation by Calspan UB Research Center and the University of Buffalo. The ITS elements evaluated in the ITSOAM software are:

- Advanced traveler information systems including dynamic message signs (DMS), highway advisory radio (HAR), information kiosks, and other non-subscription information services.
- Detection sensors and surveillance systems
- Highway emergency service patrol

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[11] "ITS Deployment Analysis System (IDAS) User's Manual," Prepared for the Federal Highway Administration by Cambridge Systematics, Oakland, CA, November 2001.

[12] Thill, C. and G. Rogova "The ITS Options Analysis Model: Technical Documentation (Version 4.101305)," or the New York State Department of Transportation by Calspan UB Research Center and University at Buffalo, Buffalo, NY, 2005.

- Adaptive ramp metering
- Adaptive traffic control systems
- Road weather information systems
- Weigh-in-motion

ITSOAM does not calculate the benefit/cost ratios of ITS deployment alternatives. Rather, it estimates the benefits of the alternatives.

Three types of information are used for the benefits models in ITSOAM:

- ***Domain knowledge information:*** This information contains data related to traffic operation and the geometry of the transportation system such as road network attributes and historical travel parameters. Travel parameters include travel time, average number of incidents, traffic composition (commuters, non-commuters, and commercial vehicles), roadway capacity, number of lanes, characteristics of different categories of delay, information on different categories of incidents, etc.
- ***Constants***: These parameters represent the use of ITS elements and proportional improvements due to these ITS elements. The literature bases average values on simulation and operational test results. Examples of these parameters include the number of travelers willing to divert as a result of information obtained from DMS and/or HAR messages and percentage change in travel time due to adaptive signal control.
- ***Variables:*** The user of the model can define a number of variables during evaluation including additional baseline information and attributes of the ITS deployment.

The ITSOAM user guide recommends an analysis of the sensitivity of the model results to the assumed values for the evaluation parameters.

2.3.3 SCRITS

SCRITS (SCReening for ITS)[13] is a spreadsheet analysis tool for estimating the benefits and costs of ITS. SCRITS is structured in a Microsoft Excel workbook format and requires the user to provide baseline data from other local sources such as count data and demand forecasting model data. Examples of SCRITS inputs include vehicle miles traveled and vehicle hours travelled. SCRITS produces benefit estimates based on total daily data. The only analysis that uses peak period analysis is the ramp metering analysis.

Sixteen ITS applications are included in the SCRITS spreadsheet. The SCRITS manual states that applications were selected based on “a prioritization of analysis needs and an assessment of information available to use as the basis for analysis.” The sixteen applications included in the SCRITS spreadsheets are:

[13] “User’s Manual for SCRITS, Screening Analysis for ITS,” Prepared for Federal Highway Administration Office of Traffic Management and ITS Applications Prepared by Science Applications International Corporation January, 1999.

- Closed circuit television (CCTV),
- Detection,
- Highway advisory radio (HAR),
- Variable message signs (VMS),
- Pager-based systems,
- Kiosks,
- Commercial vehicle operations (CVO) kiosks,
- Traffic information over the Internet,
- Automated vehicle location (AVL) systems for buses,
- Electronic fare collection for buses,
- Signal priority for buses,
- Electronic toll collection,
- Ramp metering,
- Weigh-in-motion (WIM) systems,
- Highway/rail grade crossing applications, and
- Traffic signalization strategies.

2.4 Time-of-Day Modeling

One of the most important factors taken into account when evaluating ITS, is the time period used for the analysis. IDAS allows the analyst to perform the analysis for the peak hour, peak period, or daily traffic by inputting trip matrices produced for these periods by the used demand model. ITS assessments are more realistic when done on a time-of-day basis. Because of this, it is recommended to perform the analysis based on a peak-hour or peak-period basis rather than on a daily basis. The benefits from the demand models need to be assessed based on various periods during the day and the benefits have to be summed overall the analysis time periods.

The time-of-day factor (TODF) has been defined as the ratio of vehicle trips made in a time-of-day period (or hour) to vehicle trips in some given base period, usually one day. If applied prior to trip assignment, these time-of-day factors are usually determined from household activity/travel survey data and from on-board transit and intercept auto surveys, with a separate TODF for each trip purpose. If applied after assignment, they are generally estimated from traffic data (e.g., 24-hour machine counts on streets and highways, transit counts, or truck counts), perhaps interpreted and adjusted based on data from special studies (e.g. travel surveys of workplaces and customer-serving businesses in a particular area or driveway counts at major activity centers). Occasionally, time-of-day factors are borrowed from other areas and adjusted during the model calibration process.

In order to proceed from the initial daily trip generation estimates to the volume estimates by time period, the average daily travel estimates must be converted to trips by time period. This time-of-day assignment can occur at four instances during the modeling process:[14]

1. After trip assignment: In the after trip assignment method, the assigned daily link volumes are factored to produce volume estimates by time of day. This method is the simplest and probably the most commonly used. The post-assignment static technique uses a daily traffic assignment as a basis. In its simplest form, peak hour factors (usually in the range of 8 to 12 percent) are used to reflect peak period link-level travel demand. In this approach, the daily assigned volumes are multiplied by the peak period factor to estimate peak period demands. This technique can be refined to reflect different peak hour percentages. A directional split percentage derived from observed traffic conditions can be applied to obtain link-level peak volumes. This procedure yields only a rough approximation of link or corridor level peaking.

2. Between mode choice and trip assignment: peak-hour trip tables are used as inputs to time period-specific trip assignments. The Jacksonville model developed for the Jacksonville Transportation Authority (JTA) is an example of how this approach is utilized. This model was produced and validated for the AM and PM peak periods. In other regions, models have been produced for the AM, PM, and off-peak periods. Daily traffic volumes are produced by adding up the results of the morning, afternoon, and off-peak period traffic assignments. The process for preparing peak hour directional trip tables requires the factoring of the daily person or vehicle production-attraction formatted trip tables to peak hour (or period) origin-destination formatted vehicle trip tables. The required data include an hourly distribution of trips throughout the day. These should be aggregated by trip purpose, usually grouped into home-based work, home-based non-work, and non-home-based trips. From this distribution of trips, factors are developed that represent the percentages of the trips (by purpose) during each hour and for each direction, production-to-attraction and attraction-to-production. The hourly distribution is developed from local travel survey data. The production-attraction formatted trip tables are multiplied by the appropriate factors and transposed where necessary to produce balanced origin-destination trip tables.

3. Between trip distribution and mode choice: In this method, the total daily person trip tables by purpose are divided into total person trip tables by purpose for each time period. These estimates are then used as inputs to time period specific mode choice models. Directional splits (e.g., home to work vs. work to home) must be determined as part of this process. If peak period to peak hour conversions are also done at this point, a second set of factors must be implemented.

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[14] Pendyala, R.M., "Time of Day Modeling Procedures for Implementation in FSUTMS," Final Report, BC353-08, Prepared for the FDOT by University of South Florida, December 2002.

4. Between trip generation and trip distribution: This process factors the daily trip productions and attractions by purpose and zone to produce trip end estimates by purpose and zone for each time period. These estimates are then used as inputs to time period specific trip distribution and mode choice models. Directional splits (e.g., home to work vs. work to home) must be determined as part of this process. If peak period to peak hour conversions are also done at this point, a second set of factors must be implemented.

2.5 Performance Measures Produced by Sketch Planning Tools

Existing sketch planning tools calculate various performance measures that can be used in the assessment of ITS alternatives. Table 2-1 presents a summary of the performance measures that these sketch planning tools calculate. The following subsections present a more detailed discussion of these measures.

Table 2-1 Comparison of Performance Measures Produced by Existing Sketch Planning Tools

Performance Measure	IDAS	SCRITS	ITSOAM
Mobility			
Time Savings	√	√	√
Travel Time Reliability	√		
Safety			
Accident	√	√	√
Vehicle Operation			
Fuel Consumption	√	√	√
Non-fuel Operation Costs	√		
Environment			
Emissions	√	√	√

Note: IDAS actually calculates travel time reliability as non-recurring delay.

2.5.1 IDAS

IDAS has a benefits module that estimates the impacts resulting from the deployment of ITS components. These impacts are quantified using various performance measures of travel time, travel time reliability, throughput, safety, emissions, energy consumption, and noise.

The travel time/throughput submodule determines the impacts in transportation system capacity and operational efficiency resulting from the deployment of ITS improvements. The travel time/throughput submodule is capable of determining the impacts on traveler responses including route diversion, mode shift, temporal diversion, and induced/foregone demand.

Using the performance statistics generated from the travel time/throughput submodule, the environment submodule in IDAS estimates environmental performance measures by using a series of detailed look-up tables that consider emissions and energy consumption rates by specific network volume and traffic operating characteristics. IDAS incorporates emissions and energy consumption rates from currently available sources, including Mobile 5a and the California Air Resources Board EMFAC.

The IDAS safety submodule provides estimates of the number and severity of accidents. Based on performance statistics calculated from the travel time/throughput submodule, the safety submodule determines the safety benefits of ITS by using detailed accident rates incorporated in look-up tables.

Improvements to incident delays are estimated in IDAS by a post-processor immediately following the completion of the final assignment. Separate estimates are produced for the control alternative and ITS option.

The performance measures produced by IDAS are:

- Vehicle miles of travel (VMT)
- Vehicle hours of travel (VHT)
- Average speed
- Person hours of travel (PHT)
- Number of person trips
- Number of accidents
    - Fatality
    - Injury
    - Property damage only
- Travel Time Reliability (hours of unexpected delay)
- Fuel Consumption (gallons)

- Emissions
    - Hydrocarbon and reactive organic gases
    - Carbon monoxide
    - Oxides of Nitrogen
    - PM10
    - Carbon dioxide
    - Sulfur dioxide

2.5.2 ITSOAM

ITSOAM includes the evaluation of a number of performance measures as follows:

- Travel time/delay reduction benefits
- Safety benefits
    - Reduction of the number of accidents (primary or secondary)
    - Reduction of number of fatalities
    - Reduction of accident cost
- Emission and fuel consumption benefits
    - Reduction of VOC emission
    - Reduction of NOx emission
    - Reduction of CO emission
    - Reduction of fuel consumption

2.5.3 SCRITS

The primary measures of effectiveness calculated by SCRITS vary by individual application, but generally include the following:

- Travel time in vehicle-hours
- Total travel in vehicle-miles
- Emissions (CO, NOx, HC)
- Vehicle operating costs
- Energy consumption
- Number of accidents
- Economic benefit and benefit/cost ratio

2.6 Identified Planning Measures for ITS Evaluation in Florida

The Florida's ITS Strategic Plan[15] was developed to provide a vision for the growth of ITS and the ITS Program for the State of Florida. The goals contained in Florida's ITS Strategic Plan are based on the goals set forth in the 2020 Florida Transportation Plan and the National ITS program plan. The goals and objectives contained in Florida's ITS Strategic Plan can be used as a basis for planning of ITS. These goals and objectives are:

- Safe transportation for residents, visitors, and commerce
- Preservation and management of Florida's transportation system
- A transportation system that enhances Florida's economic competitiveness
- A transportation system that enhances Florida's quality of life
- An integrated, effective system
- A well prepared and secure transportation system

As mentioned earlier in this report, a number of evaluation criteria were identified in a previous FDOT study to rank ITS alternatives and to assign weights to these criteria.[16] The criteria and weights were selected based on the results from a meeting of FDOT ITS engineers conducted as part of the Florida ten-year ITS cost-feasibility plan to identify the ITS project evaluation criteria and their weights and the review of Florida's ITS strategic plan, goals and objectives.

This section discusses the selected ranking criteria that could be evaluated using sketch planning tools like IDAS:

- <u>Safety:</u> One of the major goals of both the national and Florida ITS programs is reducing accidents and accident severity. A weight of 20 percent was associated with this measure. IDAS computes the impacts of ITS deployments on the number of fatality accidents, injury accidents, and PDO accidents.

- <u>Congestion/Mobility:</u> Efficiency and mobility are important goals of the national and Florida ITS programs. A weight of 25 percent was assigned to mobility measures such as travel time and travel time reliability.

- <u>Environment and Energy Measures:</u> Florida's ITS strategic plan goals include the need to provide transportation solutions, which enhances the quality of life. This

[15] "The 2005 Update of Florida's ITS Strategic Plan," Final Report Prepared by FDOT ITS Division, Tallahassee, FL, December 2, 2005.

[16] Hadi, M.A., D. Quigley, P. Sinha, and A. Krishnamurthy, "Intelligent Transportation Systems Deployment Analysis System Customization," Final Report Prepared for the FDOT by PBSJ, Inc., Tallahassee, FL, October 27, 2005.

includes preserving the environment and saving energy. IDAS estimates the reduction in emissions, noise, and fuel consumption for each ITS alternative. A weight of 10 percent was assigned to these measures. Of special note, a direct relationship exists between these measures and the congestion/mobility measures.

- Agency and User Costs Measures: This criterion is meant as one measure of the ability of the ITS alternatives to satisfy the economic competitiveness goal of the ITS strategic plan. It includes savings in agency costs due to increased efficiency with ITS deployments. The weight assigned to this measure is five percent.

Some of the measures selected for ranking ITS alternatives cannot be quantified using the sketch planning tools off-model calculations in combination with the results obtained using the sketch planning model calculations.

Evacuation Operations: This measure reflects the evacuation demand on the facility, its ability to accommodate the estimated evacuation demand, and the number of evacuation scenarios in which the volumes on these facilities reach a critical level. These attributes could be estimated using an evacuation demand estimation tool such as that developed by PBS&J, Inc. for the U.S. Army Corps of Engineers (USACE). The score for a given facility segment was assigned based on an evacuation demand level for facility i (EDL_i) as defined below:

$EDL_i = SVR_i * NSF_i$

where:

SVR_i = the service volume ratio or the ratio of the predicted total evacuation demand (i.e., volume) to the hourly capacity of a particular segment i as obtained from the demand estimation tool developed for the USACE, and

NSF_i = a factor defined to reflect the number of evacuation scenarios in which the SVR on the facility is expected to have an SVR of at least 16.

A weight of 15 percent was used for this criterion.

Commercial Vehicle Operations: This measure reflects the ITS benefits to Commercial Vehicle Operations (CVO). The scores can be assigned based on the relative values of the truck volumes on the investigated highway segments. A weight of five percent was used for this criterion.

Special Event Generators: This criterion reflects the use of highway segments by major special event attendees in Florida. The scores for the highway facilities can be assigned based on the estimated relative values of the special event volumes on the investigated highway segments, with a score of 100 percent given to the segment that has the highest estimated volume. A weight of 10 percent was used for this criterion.

Programmed Capacity Improvements: The rationale for this criterion was that, from a production standpoint, ITS deployments should ideally be constructed at the same time as the capacity improvements. Also, the coordination of ITS deployments during roadway widening or reconstruction would assist in leveraging valuable design and construction dollars. ITS devices could also help in work zone management during construction. Scores were assigned to ITS projects based on scheduled capacity improvements by the FDOT fiscal year. A weight of 10 percent was used for this criterion.

2.7 IDAS Assessments and Case Studies

This section elaborates on previous studies that have used and/or evaluated IDAS. The results from these studies shed light on important issues in the use of sketch planning tools in general and IDAS in particular for sketch planning level evaluation of ITS.

2.7.1 Northeastern Illinois Evaluation[17]

The purpose of the Northeastern Illinois case study conducted by Chicago Area Transportation Study (CATS) was to test the capabilities of IDAS. Four types of ITS deployments were investigated: electronic toll collection, freeway variable message signs, electronic transit fare collection system, and transit vehicle signal priority. Since the study aimed at checking IDAS capacities, the default impact values were used in the analysis, but the dollar values of the benefits were increased by 18.5 percent according to the Consumer Price Index (CPI) to express the benefits in 2002 dollars.

To validate the IDAS traffic assignment for the base case, the study used the root-mean-square error of the volumes on the links with more than 39,000 vehicles and the total vehicle-miles traveled (VMT). The study showed that the traffic assignment results were reasonable. Four discrepancies were identified based on the results that appear to be due to computer programming errors. As a response to the findings of this paper, the developer of IDAS addressed three of the issues. However, the fourth issue (the assignment of truck volumes to truck-restricted links) was a problem in traffic assignment and could not be corrected in the near-term.

Other identified issues were that the electronic toll collection deployment could not be modeled on a lane-by-lane basis but had to be calculated for the whole link. In addition, the calculation of incident delays depended only on link V/C ratio, number of lanes and VMT, but not on the number of incidents occurring on that link. Moreover, travel time reliability was estimated only for the freeway due to the lack of data for the arterial roadways.

The Northern Illinois study report found that IDAS did a better job in modeling ITS deployments for highways than those for transit because it can only model transit outcomes at a zonal level rather than transit network assignments.

[17] Heither, C. and M. Thomas, "Testing of IDAS Capabilities Using Northeastern Illinois ITS Deployments," Working paper 03-06, August 2003.

Based on these considerations, the report suggested CATS should incorporate certain IDAS methodologies as part of the CATS regional travel demand model instead of using IDAS per se. This would have the following advantages:

- Consistency of reporting measures such as including the emissions resulting from vehicle cold starts
- Reduction of duplication of effort on converting the network files and demand matrices into the format required by IDAS
- Direct reporting of analysis results without modifications such as restricting the reporting area and converting truck traffic into vehicle trips instead of vehicle-equivalent trips
- Better analysis of transit deployments, for example, analysis of the transit signal priority based on specific bus routes and congestion time based on highway assignment.

Although experts from the IDAS development team and FHWA agreed with most of these points, they also mentioned that IDAS advantages include the more than 60 ITS components it considers in its modeling matrices and that this model continually updates impact values, equipment costs and equipment inventories.

2.7.2 Ohio-Kentucky-Indiana Evaluation[18]

This effort used IDAS in the evaluation of Advanced Regional Traffic Interactive Management Information System (ARTIMIS) project evaluation, and the enhancements of the ARTIMIS project. The evaluated ARTIMIS included the following ITS components: closed circuit TV cameras (CCTV), electronic dynamic message signs (DMS), traveler advisory telephone service (TATS), highway advisory radio (HAR) freeway service patrol vans, ramp and reference markers, vehicle detectors, total station electronic surveying equipment, and operations control center (OCC). The planned year 2006 enhancement included arterial operations upgrades, airport kiosks, advanced public transportation systems, traveler information for truck, emergency vehicle traffic signal preemption, freeway bridge snow and ice removal, incident management components, highway-rail intersection safety systems, and expansion of traveler information delivery. The planned year 2010 enhancement further expanded the deployment of ITS elements to include ramp metering, road weather system, parking management system, and red-light running enforcement system.

Data obtained from the Ohio-Kentucky-Indiana (OKI) regional travel demand model were used to produce the inputs to IDAS. The analysis included AM and PM peak periods. Careful considerations were given to match the ITS components to IDAS

[18] "Ohio-Kentucky-Indiana Regional Council of Governments' Evaluation of ARTIMIS and ITS Program Plan, ITS Deployment Analysis System (IDAS)," U.S. Department of Transportation Federal Highway Administration, January 10, 2002.

categories, since some categories (like freeway snow and ice removal) were not considered in IDAS. As one critical step, some default impact values in IDAS were adjusted to reflect the local conditions—for instance, the reduction in incident duration was decreased from 55 percent to 22.5 percent, and the reduction in emissions and fuels was dropped from 42 percent to 17.2 percent for the incident management system. The market penetration of telephone and web information services was changed from the default of 1 percent to 0.42 percent, and the time savings due to the dynamic message signs was increased from 3 minutes to 17 minutes per diverted traveler. The percent of vehicles that tuned to the HAR broadcast was dropped to 5 percent from the default of 25 percent, and the percent time of extreme conditions for highway advisory radio was decreased from 10 percent to 2 percent. The IDAS analysis results showed that the application of ARTIMIS could achieve annual benefits of $135,850,000, indicating a benefit/cost ratio of 12:1. The year 2006 and 2010 enhancements could also result in a benefit/cost ratio of 12:1 and 9:1, respectively.

Based on the IDAS analysis results, some improvements to the ARTIMIS system were identified. For example, the incident management system generated the greatest benefits of the ARTIMIS system, indicating that the investment in this system should increase. The other recommendations included the increase of market penetration of telephone/web traveler information systems, improvement in the operability of HAR, increase of dynamic message sign deployment, improvement in live video feed availability to the emergency responders and public, and the expansion of freeway service patrol.

2.7.3 Michigan Case Study[19]

The Michigan Department of Transportation (MDOT) deployed the Temporary Traffic Management System (TTMS) to address the congestion resulting from an I-496 reconstruction project. The ITS technologies used in TTMS included closed circuit television cameras (CCTV), portable dynamic message sign (PDMS), detection devices for traffic queuing and construction zones, video monitoring stations, telephone/web-based traveler information, and a traffic management center (TMC). Besides these technologies, the signals on major alternative routes were also upgraded. MDOT applied IDAS to investigate the impacts of TTMS system on the roadway network and the benefits associated with it.

The analysis considered two phases of construction and each phase consisted of three time periods: AM peak period, PM peak period, and an off-peak period that aggregated all other time periods. The IDAS inputs for the network and travel demand matrices were obtained from the Tri-County Regional Planning Commission (TCRPC) demand forecasting model. Some impact values and dollar values were adjusted according to local conditions, as listed in Table 2-2 and Table 2-3.

[19] "Case Study 2: Michigan Department of Transportation Evaluation of the Temporary ITS for the Reconstruction of I-496 in Lansing, Michigan, ITS Deployment Analysis System (IDAS)," U.S. Department of Transportation Federal Highway Administration, April 25, 2002.

Table 2-2 Adjusted Impact Value for the Lansing I-496 Evaluation

Impacts	IDAS Default	Adjusted Value
Incident Management System		
Reduction in incident duration	55%	20%
Reduction in fatalities	10%	6%
Reduction in emissions and fuel	42%	6%
Telephone and Web Information Services		
Market penetration	1%	1.4%
Time savings per traveler	15%	20%
Signal Coordination		
Central control corridor signal coordination	6-18%	14%
Preset timing corridor signal coordination	8-25%	8%

Table 2-3 Dollar Values of Benefits Used in the Lansing I-496 Evaluation

Effective Measures	IDAS Default	Adjusted Value
In-Vehicle Travel Time		
Commercial trucks	$16.96 per hour	$20.80 per hour
Auto	$9.63 per hour	$8.50 per hour
All other modes	$8.90per hour	$8.50 per hour
Out-of-Vehicle Travel Time		
Commercial trucks	$16.96 per hour	$20.80 per hour
All other modes	$17.00 per hour	$17.00 per hour
Fuel Costs		

Effective Measures	**IDAS Default**	**Adjusted Value**
Auto	$1.21 per gallon	$1.21 per gallon
Commercial trucks and buses	$1.15 per gallon	$1.15 per gallon
Non Fuel Operating Costs		
Auto	$0.061 per vehicle mile	$0.03 per vehicle mile
Commercial trucks	$0.245 per vehicle mile	$0.10 per vehicle mile
Accident Costs		
Fatality		
All modes – internal costs	$2,317,398.00 per fatality	$2,317,398.00 per fatality
All modes – external costs	$408,952.00 per fatality	$408,952.00 per fatality
Injury		
All modes – internal costs	$50,760.00 per incident	$50,760.00 per incident
All modes – external costs	$8,958.00 per incident	$8,958.00 per incident
Property Damage Only		
All modes – internal costs	$2,824.00 per incident	$2,824.00 per incident
All modes – external costs	$498.00 per incident	$498.00 per incident
Emissions		
All modes – hydrocarbons	$1,774.00 per ton	$1,774.00 per ton
All modes – nitrous oxides	$3,731.00 per ton	$3,731.00 per ton
All modes – carbon monoxide	$3,889.00 per ton	$3,889.00 per ton
All modes – particulates	$11,066.00 per ton	$11,066.00 per ton
All modes – carbon dioxide	$3.56 per ton	$3.56 per ton

The IDAS analysis results showed that the I-496 reconstruction project would shift the traffic from the Interstate to local arterials, which in turn, increased the travel time, accidents, fuel consumption, and emissions. On the other hand, deploying TTMS and upgrading arterial signals may mediate such adverse impacts and result in a benefit/cost ratio of 3.2:1.

2.7.4 Hampton Road Case Study[20]

The Hampton Roads region in Virginia is a major tourist destination with increasing congestion problems. To assess potential solutions, ITS technologies, especially incident management systems, were evaluated using IDAS. The study only focused on the emissions benefits of incident management systems.

Two types of ITS components were included in the IDAS analysis: Incident Detection/Verification, and Combination Incident Detection and Response. The IDAS analysis consisted of three scenarios: 1) the base case without ITS components, 2) current ITS deployment, and 3) future improvements. In IDAS, the default values for the emission reduction on affected link are 15 percent for incident detection/verification system and 42 percent for the combined incident detection/verification and response/management system. Although the analysts were not satisfied using the same reduction rates for different pollutants, due to the lack of data the default impact values were used in the analysis.

IDAS analysis results showed that the implementation of incident management systems may reduce emissions, however, its magnitude (9-14 percent) was considered too high. To evaluate the IDAS results, an alternative method was applied to calculate emissions, which was based on the number of incidents and emission reduction per incident based on the experience of the San Francisco Bay Area—that is, the analysis utilized a predicted value of 70 lb/day for HC, 710 lb/day for CO, and 1758 lb/day for NOx. The results of the alternative approach showed a reduction of 6.8 tons per day in NOx emissions and a reduction of 2.7 tons per day in HC emissions, which was 38 percent lower than the IDAS results.

Finally, the IDAS-calculated emission benefits were not accepted due to following concerns:

- The emission benefits were directly estimated based on the outputs of the travel demand model, which was not consistent with the traditional emission analysis requiring post-process of travel demand model output.
- The analysts were not convinced of the appropriateness of using the same impact values for different pollutants.

[20] "Case Study 3: Evaluation of Emissions Impacts of an Incident Management System in Hampton Roads, Virginia, ITS Deployment Analysis System (IDAS)," U.S. Department of Transportation Federal Highway Administration, July 2, 2002.

- Furthermore, the IDAS calculation of the reduction in emissions due to non-recurrent congestion cannot be validated.

To finish the evaluation task, a traditional analysis approach, which was originally developed to evaluate the benefits of a light-rail system in the region, was employed to calculate the emission benefits. The results of this approach were less than 5 percent of the IDAS values.

2.7.5 Kansas City Study[21]

An Enhanced Congestion Management System (CMS) was developed for the Kansas City, Missouri Region in 1999 to mitigate area congestion levels. The report explained that the IDAS analysis covered a freeway incident management system, highway information system (consisting of highway advisory radio and dynamic message signs), and telephone/internet-based advanced traveler information system.

The results showed that the deployment of an incident management system could yield a 7.2 percent reduction in incident delay in this region and a 40 percent reduction within the study area (a highly congested subarea of the region). The safety benefits associated with incident management system were 0.3 percent and 4 percent reduction in the number of fatalities region-wide and within the study area, respectively. The associated environment and energy benefits were 0.8-1.0 percent reduction in emissions and fuel consumption in the region, 10-11.7 percent reduction in emissions, and 11.8 percent decrease in fuel consumption for the subarea. The daily time savings resulted from the highway information system was estimated to be 690 vehicle-hours and the daily saving from the application of ATIS was estimated to be 56 vehicle-hours.

2.7.6 Wisconsin ITS Benefit Assessment Study[22]

The formal ITS program in Wisconsin has been in place since 1993. By 2001, the planning and program-level resources have been determined for a 10-year timeframe. In 2002, however, as the Wisconsin Department of Transportation (WisDOT) moved toward the development of specific design criteria, a need was identified for more detailed benefit/cost analysis tools to enable engineers and other practitioners to make more informed decisions comparing one type of solution to another. Table 2-4 shows the parameters used in this study.

A project was initiated to identify methodologies to assess the ITS benefits and costs that are appropriate for use in Wisconsin and to recommend a set of tools to be tested. Their

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[21] "Mid-American Regional Council's Enhanced Congestion Management System, ITS Deployment Analysis System (IDAS)," U.S. Department of Transportation Federal Highway Administration, July 2, 2002.

[22] "Development of Methods for Benefits Assessment of ITS Deployment in Wisconsin," Prepared for Wisconsin DOT by Cambridge Systematics Inc., Final Report No. 0092-02-16, July 2004

literature search identified three levels of tools that can be applied for the evaluation of ITS benefits:

- A network-based tool that can utilize regional travel demand models, or other network-based data and evaluate benefits at the regional or corridor level. The ITS Deployment Analysis System (IDAS) was identified as the most advanced tool for this purpose.
- A traffic simulation technique that can evaluate operations in greater detail on freeway and major arterial corridors.
- A spreadsheet-based technique for use in stand-alone or limited ITS deployments, or for use in areas where travel demand models are not available.

Table 2-4 Parameters Identified in Wisconsin Study

Impact Measure	IDAS National Defaults	Proposed Value
Freeway Service Patrol		
Reduction in incident duration	55%	55%
Reduction in fatalities	10%	6%
Reduction in emissions and fuel	42%	5%
Incident Management System[a]		
Percent time sign is on and disseminating information	10%	2.5%
Percent vehicles that save time	20%	20%
Time savings	3 minutes	3 minutes
Dynamic Message Signs[b]		
Percent time sign is on and disseminating information	10%	1%
Percent vehicles that save time	20%	20%
Time savings	3 minutes	3 minutes
Central Corridor Traffic: Signaling in High-Intensity Areas		
Capacity change on affected progression links	8%	8%
Traffic Actuated Traffic Signaling In Low-Intensity Areas		

Impact Measure	IDAS National Defaults	Proposed Value
Capacity change on affected progression links	16%	16%
Capacity change on affected cross-flow links	-16%	-16%
Ramp Rollover Systems		
Percentage of traffic considered commercial	N/A	10%
Percentage reduction in accident rates	100%	45%
Portable Traffic Management Systems		
Percent time sign is on and disseminating information	10%	2%
Percent vehicles that save time	20%	20%
Time savings	3 minutes	3 minutes
Highway Advisory Radio		
Percent vehicles tuned into broadcast	25%	5%
Percent vehicles that save time	25%	25%
Percent time of extreme conditions	10%	2%
Time saving per traveler	4 minutes	4 minutes
Ramp Metering		
Capacity change on freeway	13.5%	13.5%
Capacity change on ramps	-50%	-50%
Accident reduction on freeway	-38%	-38%
Accident reduction on ramps	-38%	-38%

[a] This deployment is modeled after a Dynamic Message Sign deployment. The intent is that at either end of the affected section of roadway (or within the section), there will be notifications of some incident, and traffic will be diverted to parallel (or associated) arterial. The effect is the same as notification via DMS.

[b] These deployments are generally in parallel with the Incident management (IM) deployments, full impacts values here would likely double count those from the IM deployments.

3 Supporting Models

Sketch planning tools require base modules to estimate traffic demands and performance measures based on network geometry and traffic operation parameters. As indicated earlier in this document, IDAS includes a number of these modules. Some of the required modules are already available in the FSUTMS including traffic assignment, mode choice, and travel time estimation. FSUTMS estimates travel time based on link traffic demand and capacity using Bureau of Public Road (BPR) curves that are calibrated for each Florida region. The modules available in the FSUTMS will be used in the tool developed in this study. Other modules required to calculate the performance measures are not currently available in the FSUTMS. These include the emissions, fuel consumption, and safety modules. First, this chapter presents a review of potential emission, fuel consumption, and safety modules. Then, it gives recommendation regarding the selection of such models for implementation in the developed tool.

3.1 Emission Estimation

The three sketch planning tools reviewed earlier in this document estimate emissions based on factors derived from default emission models. Mobile6 is the latest motor vehicle emission factor model used to estimate volatile organic compounds, nitrogen oxides (NOx) and carbon monoxide (CO) from different vehicle types. This model considers both vehicle performance and driver behavior while estimating motor vehicle emissions. Mobile6 predicts higher emission rates in near future years and lower emission rates in out years when compared to the earlier Mobile5 series model.

IDAS includes look-up tables (by year from 2000 to 2040) that incorporate available emission rates from the Federally-sponsored Mobile5a and CARB-sponsored EMFAC models. IDAS default Mobile5a emission rate look-up tables are based on Chicago region rates that were categorized by speed range, pollutant type (HC, CO, NOx), and eight vehicle type categories. For use in California, IDAS also contains EMFAC-based emission rate look-up tables by pollutant type (ROG, CO, NOx, PM10, CO2, and SO2), vehicle type, and speed range. Emission rates estimated at speeds of 2.5 mph (4 kph) are considered idle emission rates. The IDAS user is also required to input percentages of each vehicle type for each market sector.

The emis_fac lookup table in SCRITS contains estimates of grams per mile for three pollutants (CO, NOx, and HC. An emission factor is provided for each 5-mile increment of speed. The ITSOAM emission estimation is based on a modified version of EPA's Mobile5b model. ITSOAM reports VOC, NOx, and CO emission factors by average vehicle speeds from 2.5 mph to 65 mph and roadway functional classes.

During the FDOT Florida-specific ITS Benefit and Cost parameters project, the FDOT Systems Planning Office (SPO) responded to the research teams request for information by providing Mobile6 emission rates for the years 1999 to 2030. The provided rates were those used for the Tampa Bay area. The rates obtained from the FDOT were for vehicle speeds ranging from 2.5 to 65.0 mph (4.0 to 104.6 kph) at 5.0 mph (8.0 kph) intervals.

In this study, the research team obtained the emission rates used in the Southeast FSUTMS model.
Figure 3-1 to
Figure 3-6 show a comparison between these rates and those used by IDAS Mobile5a, SCRITS, IDAS Florida-specific emission rates (rates used in Tampa Bay as explained above and referred to as “Florida” in the figures), and IDAS EMFAC models for the years 2000 and 2030. As these figures show, the “Florida” and the Southeast Florida rates are identical. They are higher than the rates used in IDAS for the year 2000 and lower than the IDAS rates for the year 2003. Since the Florida models are based on Mobile6 runs and the IDAS rates are based on Mobile5, the above confirms a previous statement in this section that Mobile 6 predicts higher emission rates in near future years and lower emission rates in out years when compared to the Mobile5 series model.

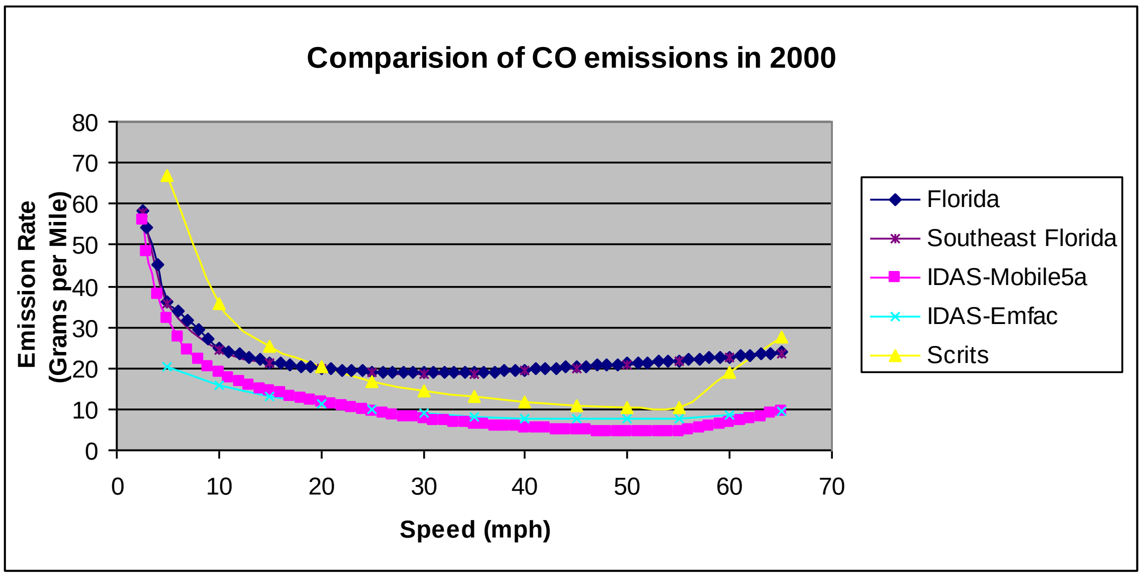

Figure 3-1 Comparison of CO Estimation by Different Models in 2000

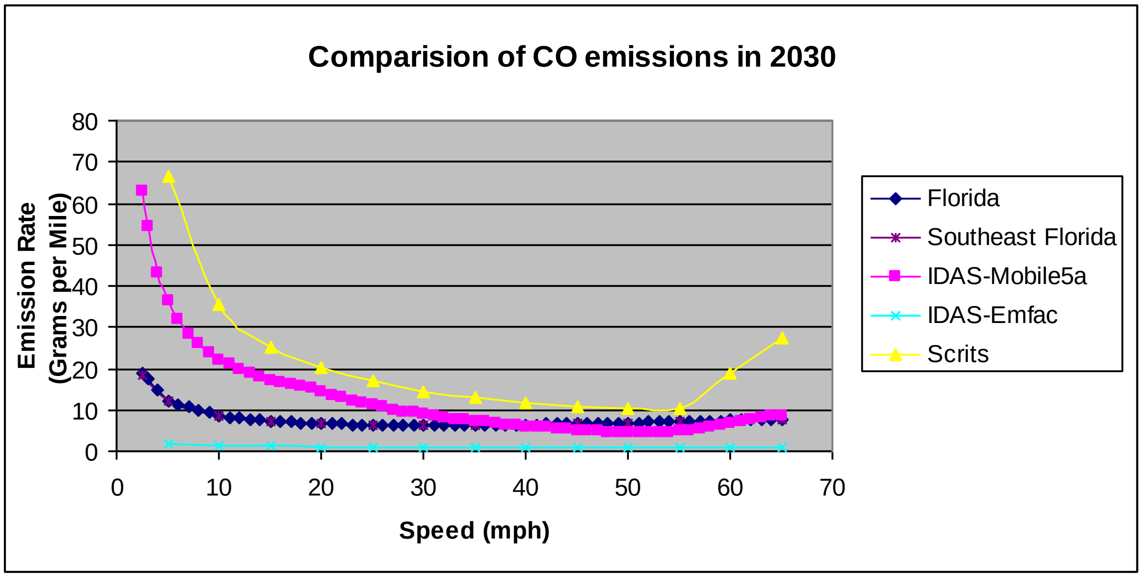

Figure 3-2 Comparison of CO Estimation by Different Models in 2030

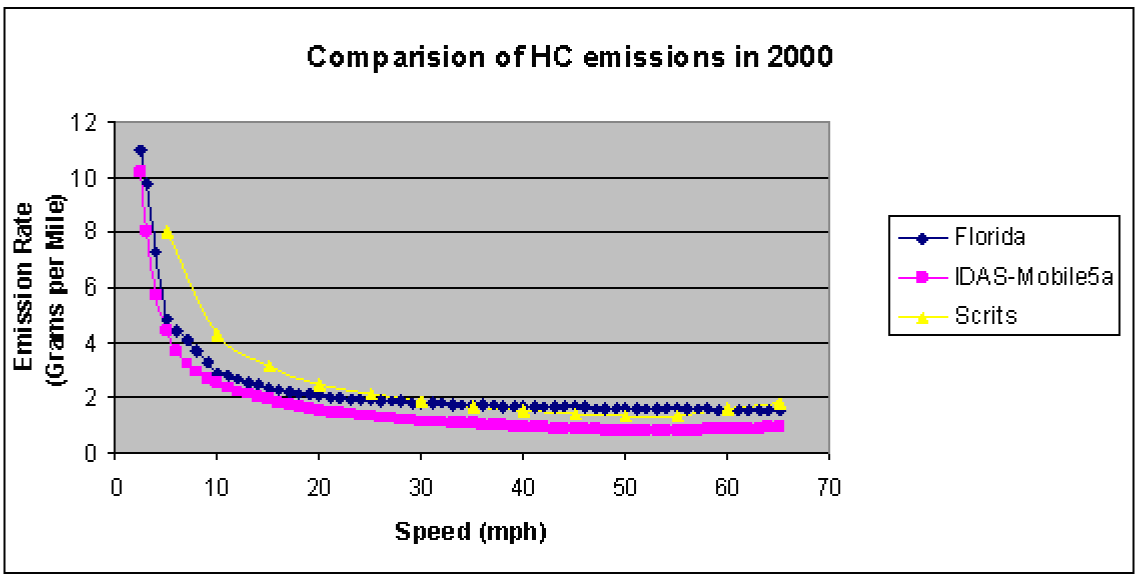

Figure 3-3 Comparison of HC Estimation by Different Models in 2000

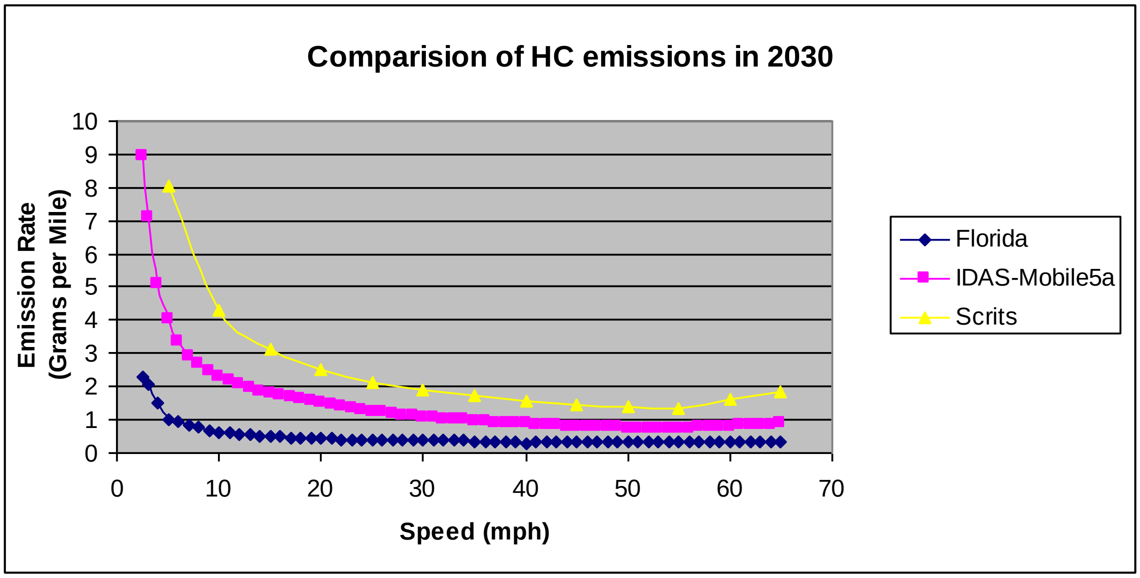

Figure 3-4 Comparison of HC Estimation by Different Models in 2030

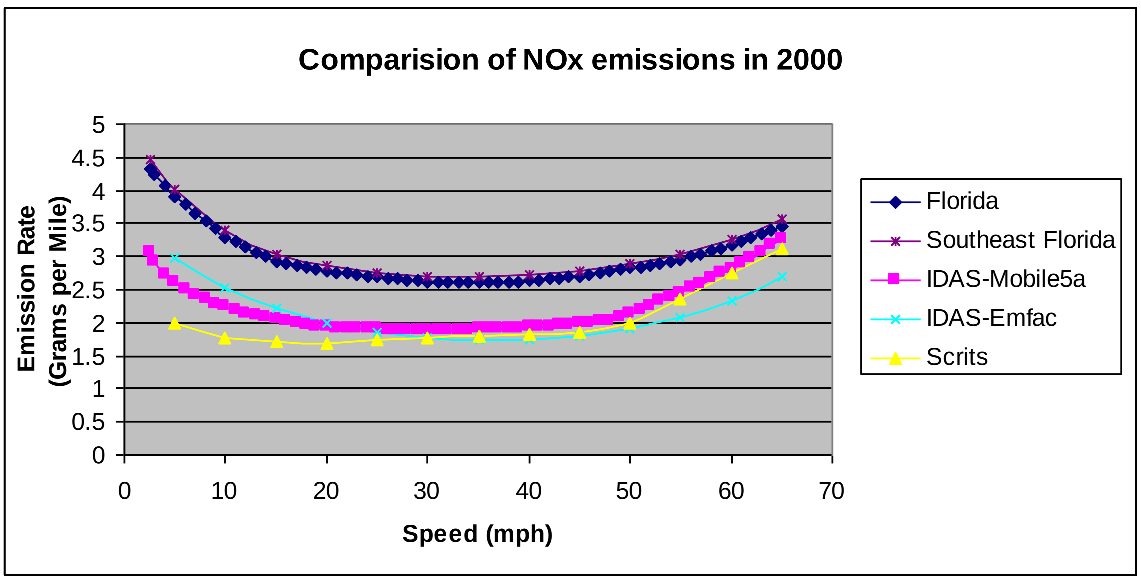

Figure 3-5 Comparison of NOx Estimation by Different Models in 2000

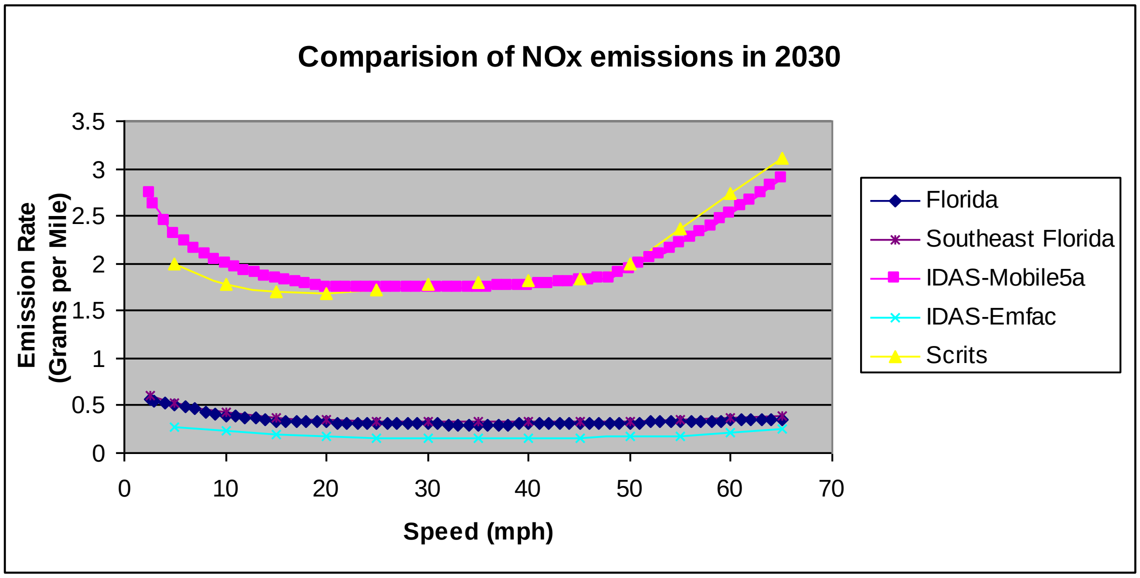

Figure 3-6 Comparison of NOx Estimation by Different Models in 2030

3.2 Fuel Consumption

IDAS estimates fuel consumption based on rates obtained from previous models. include models developed by the Environmental Protection Agency (EPA), Air Resources Board (CARB), Caltrans, and other agencies. The models were used develop lookup tables to obtain the rates in IDAS. These rates are categorized by type (freeways and arterials); speed range (zero to 70 mph, depending on facility); vehicle type (autos and trucks); and fuel type for trucks (gas and diesel).

Table 3-1 shows the fuel consumption rates used by IDAS for freeways and arterials. The average fuel consumption rates as a function of traffic speed used in ITSOAM are presented in Table 3-2. The rates presented in

Table 3-1 and Table 3-2 are compared graphically in Figure 3-7 and Figure 3-8.

Table 3-1 Fuel Consumption Rates Used by IDAS

Facility type	Speed	Auto	Truck Gas	Truck Diesel
Freeway	0	0.540	0.650	0.450
	5	0.182	0.310	0.696
	10	0.123	0.181	0.489
	15	0.089	0.135	0.297
	20	0.068	0.118	0.185
	25	0.054	0.120	0.131

Facility type	Speed	Auto	Truck Gas	Truck Diesel
	30	0.044	0.133	0.110
	35	0.037	0.156	0.112
	40	0.034	0.185	0.122
	45	0.033	0.223	0.136
	50	0.033	0.264	0.153
	55	0.034	0.310	0.170
	60	0.037	0.374	0.187
	65	0.043	0.439	0.204
	70	0.052	0.511	0.221
Arterial	5	0.144	0.275	0.383
	10	0.091	0.174	0.241
	15	0.073	0.140	0.194
	20	0.064	0.123	0.171
	25	0.059	0.113	0.157
	30	0.056	0.106	0.147
	35	0.053	0.101	0.140
	40	0.051	0.097	0.135

Table 3-2 Average Fuel Consumption Rates Used in ITSOAM

Operating Speed	Rate (Gallon per mile)	
	Auto	Truck
5	0.117	0.503
10	0.075	0.316
15	0.061	0.254

Operating Speed	**Rate (Gallon per mile)**	
	Auto	**Truck**
20	0.054	0.222
25	0.050	0.204
30	0.047	0.191
35	0.045	0.182
40	0.044	0.176
45	0.042	0.170
50	0.041	0.166
55	0.041	0.163
60	0.040	0.160
65	0.039	0.158

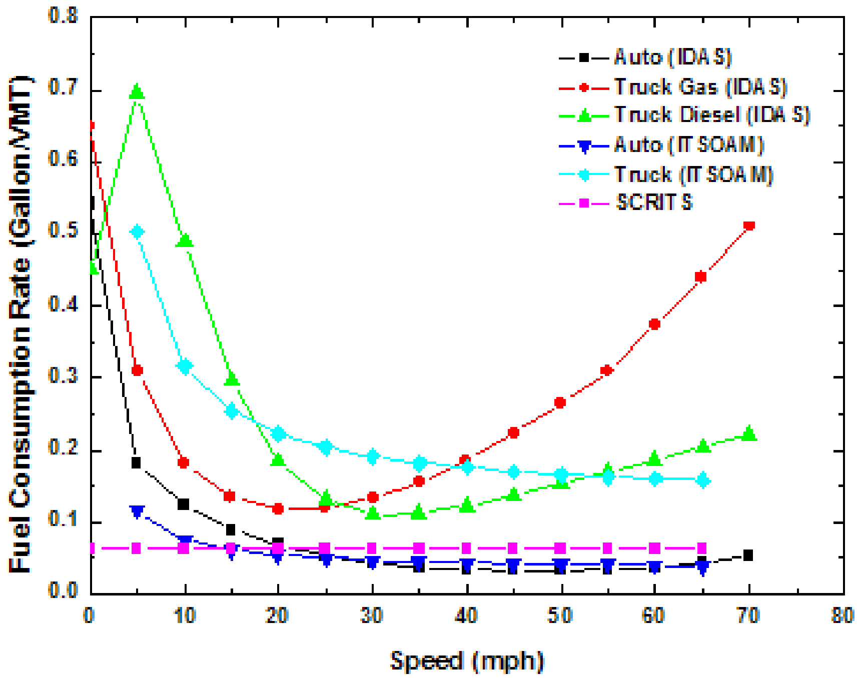

Figure 3-7 Comparison of Fuel Consumption Rates Used by Different Tools for Freeways

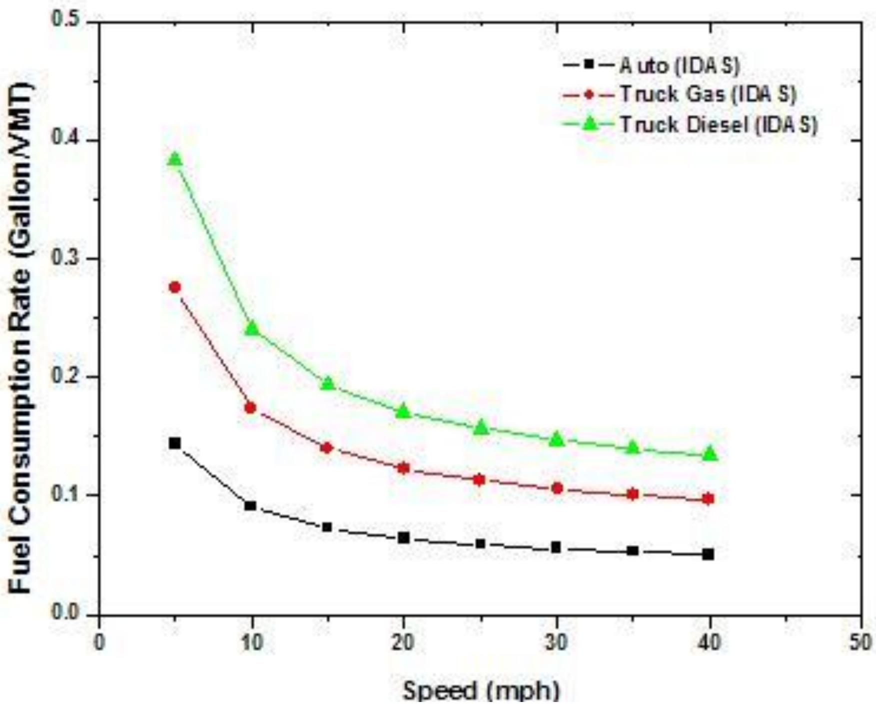

Figure 3-8 Comparison of Fuel Consumption Rates Used by Different Tools for Arterials

3.3 Safety

Another needed supporting base module is a safety module that estimates property damage only (PDO), injury, and fatality crash rates based on parameters such as traffic demand or volume/capacity (V/C) ratio. As shown in Table 3-3, IDAS includes crash rates that are functions of the facility type (i.e., freeways or arterials), V/C ratio, and vehicle type (i.e., auto or truck). Table 3-3 provides the default crash rates in terms of crashes per MVMT for different crash, facility, and vehicle types. The crash rates vary in IDAS with the V/C ratios only for freeway crashes. For arterials, the crash rates per MVMT are fixed for all V/C ratios, due to the limited studies performed on the subject.

The FDOT "Intelligent Transportation Systems Deployment Analysis System Customization" study adjusted the IDAS crash rate defaults based on the average crash rates in Florida. Only the arterial rates had to be adjusted. The default IDAS crash rates and adjusted crash rates for Florida are shown in Table 3-3 and Table 3-4, respectively.

Table 3-3 The Default Crash Rates Used in IDAS

V/C	Fatality Crashes/MVM	Injury (Crashes/MVM)				PDO (Crashes/MVM)			
		Freeway Auto	Arterial Auto	Freeway Truck	Arterial Truck	Freeway Auto	Arterial Auto	Freeway Truck	Arterial Truck
0.09	A constant of 0.0004 for freeways and 0.0066 for arterials.	0.5156	1.5724	0.5156	1.5724	0.8551	2.1949	0.8551	2.1949
0.19		0.5156	1.5724	0.5156	1.5724	0.8551	2.1949	0.8551	2.1949
0.29		0.5156	1.5724	0.5156	1.5724	0.8551	2.1949	0.8551	2.1949
0.39		0.5156	1.5724	0.5156	1.5724	0.8551	2.1949	0.8551	2.1949
0.49		0.5156	1.5724	0.5156	1.5724	0.8551	2.1949	0.8551	2.1949
0.59		0.5757	1.5724	0.5757	1.5724	0.8551	2.1949	0.8551	2.1949
0.69		0.5757	1.5724	0.5757	1.5724	0.8551	2.1949	0.8551	2.1949
0.79		0.5757	1.5724	0.5757	1.5724	0.9953	2.1949	0.9953	2.1949
0.89		0.5757	1.5724	0.5757	1.5724	0.9953	2.1949	0.9953	2.1949
0.99		0.7329	1.5724	0.7329	1.5724	1.1591	2.1949	1.1591	2.1949
1.00		0.7329	1.5724	0.7642	1.5724	1.2737	2.1949	1.2737	2.1949

Table 3-4 Adjusted Safety Module Parameters Used in the Florida IDAS Customization Study

V/C	Fatality	Injury				PDO			
		Freeway Auto	Arterial Auto	Freeway Truck	Arterial Truck	Freeway Auto	Arterial Auto	Freeway Truck	Arterial Truck
0.09	A constant of 0.0004 for freeways and 0.0072 for arterials.	0.5156	1.715	0.5156	1.715	0.8551	2.394	0.8551	2.394
0.19		0.5156	1.715	0.5156	1.715	0.8551	2.394	0.8551	2.394
0.29		0.5156	1.715	0.5156	1.715	0.8551	2.394	0.8551	2.394
0.39		0.5156	1.715	0.5156	1.715	0.8551	2.394	0.8551	2.394
0.49		0.5156	1.715	0.5156	1.715	0.8551	2.394	0.8551	2.394
0.59		0.5757	1.715	0.5757	1.715	0.8551	2.394	0.8551	2.394
0.69		0.5757	1.715	0.5757	1.715	0.8551	2.394	0.8551	2.394
0.79		0.5757	1.715	0.5757	1.715	0.9953	2.394	0.9953	2.394
0.89		0.5757	1.715	0.5757	1.715	0.9953	2.394	0.9953	2.394
0.99		0.7329	1.715	0.7329	1.715	1.1591	2.394	1.1591	2.394
1.00		0.7329	1.715	0.7642	1.715	1.2737	2.394	1.2737	2.394

3.4 Assessment

Based on the above review, the following recommendations are designed to facilitate the implementation of the default base supporting modules in the tool developed in this study.

- The emission module of the Florida-specific IDAS setup, selected as part of an earlier FDOT effort, should be used in this study.
- The fuel consumption rates used in IDAS will be used in this study since this module was established based on a number of previous studies. However, the curves of the fuel consumption rates of trucks were adjusted to eliminate the increase in fuel consumption with the increase in speed.
- The safety module used in IDAS, as adjusted for Florida conditions in the previous FDOT effort mentioned above, should be used as the default in this study.

4 Evaluation Parameters

The ITS sketch planning evaluation tools require three types of parameters: 1) the ITS impact factors, 2) cost parameters, and 3) benefit dollar values. This chapter presents a discussion of these parameters. The default impact selection factors for individual ITS components are discussed in detail in the specific chapters that evaluate each of these components (Chapters 6 to 16).

4.1 Impact Factors

IDAS includes a large number of ITS component-specific impact (benefit) factors that it maintains in a database and applies to adjust the performance measures, where appropriate, to account for ITS impacts. The IDAS developers selected the default values of these impact factors based on information obtained from reviewing ITS benefits reported in previous ITS deployment evaluation studies. This information was initially obtained based on an extensive literature review by the IDAS developers, then supplemented by data obtained from the USDOT RITA ITS Benefits Database. The results from those studies are documented in the IDAS ITS Benefits Library, which is provided with the IDAS software and sometimes referred to as the "Direct Benefits Spreadsheet." The IDAS default values might not, however, reflect updated information currently included in the RITA database or the results of recent evaluation studies. Thus, each of the impact factors will be assessed in this study (see Chapters 6 to 16) in order to select a set of impact factors that reflect the most recent evaluation results.

The RITA ITS Benefits Database documents the impacts of ITS deployments as reported in national and international ITS evaluation studies. This information is classified in several ways. One of the classification methods groups the benefits data into two major components: 1) intelligent infrastructures and 2) intelligent vehicles. These components are then categorized into program areas and specific ITS application areas. Data are also classified by various measures of effectiveness. Termed "a few good measures," USDOT identified these measures to assist in tracking the nation's progress towards meeting ITS program goals. They include safety, delay or travel-time savings, cost savings, improvements in effective capacity, customer satisfaction, and energy and environmental impacts. Additional classification methods of the benefits data include the location of the project by state or country, the types of integration between the multiple ITS applications represented by the project, and most recent updates to the data in the ITS Benefits Database.

This study extensively reviews the RITA database for each type of ITS deployments. It will be used as a basis for selecting the default values for the developed tool. The user can also use the tool to perform sensitivity analysis of the value influence on the impact parameters in the analysis results.

4.2 ITS Cost Parameters

4.2.1 The USDOT and IDAS ITS Unit Cost Database

Since December 1994, the USDOT's Joint Program Office (JPO) for ITS (currently incorporated into RITA) has been collecting information regarding the impacts of ITS projects on the operation of the surface transportation network. This information is maintained in the RITA ITS Benefits Database. The program also collects and maintains information on ITS costs in the ITS Unit Costs Database.

The JPO's ITS Unit Costs Database consists of cost estimates for a set of ITS elements. These cost estimates are categorized as capital or operations and maintenance (O&M) costs. Capital costs are the costs expended for one-time, nonrecurring purchases. Examples include, but are not limited to, the cost of equipment, system design, installation, and software development. The O&M costs, often referred to as recurring costs, are the costs that are incurred on an ongoing basis. Typical examples include the leased communication service's monthly fees, ITS equipment repairs, preventive maintenance, and labor costs. Costs are presented in the database in a range to capture the lows and highs of the cost elements from the different data sources that were used in deriving the Database. The *ITS Unit Costs Database's* website states, "The cost data are useful in developing project cost estimates during the planning process. However, the user is encouraged to find local/regional data sources and current vendor data in order to perform a more detailed cost estimate."[23]

The database was initially based on the unit costs used in the National ITS Architecture (NITSA) ITS Cost Analysis.[24] As new cost data becomes available, the unit cost elements are revised and new unit cost elements are added.

Any new cost data sources are reviewed for content and applicability to the *ITS Unit Costs Database*. These new cost databases are obtained from state and local governments and agencies, congressionally-designated ITS projects, and national ITS-related product vendors. The IDAS default cost values are periodically updated based on the JPO's ITS Unit Costs Database.

The current version of the *ITS Unit Costs Database* is dated September 30, 2006. Two types of unit costs are available: 1) unadjusted costs corresponding to the actual dollar year, and 2) adjusted costs in 2005 dollars. In order to obtain the adjusted costs, the ITS elements are classified into eight categories. For each category, the year-by-year index series are listed and applied to calculate the conversion ratio from the actual dollar year

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[23] United States Department of Transportation, Intelligent Transportation Systems Joint Program Office. Available at http://www.benefitcost.its.dot.gov/ITS/benecost.nsf/ByLink/CostHome

[24] Lockheed Martin Federal Systems, Odetics Intelligent Transportation Systems Division, Electronic Document Library (EDL) No. 5398, *ITS Cost Analysis* (January 1997). Available online at http://www.its.dot.gov/arch/DOCUMNTS.htm

into 2005 dollars. Applying these conversion ratios to the unadjusted costs yields the adjusted costs. The unadjusted and adjusted costs are presented in Table 4-1.

4.2.2 Florida Specific IDAS Cost Database

In 2004, Hadi et al.[25] identified Florida-specific defaults for the ITS equipment unit costs in IDAS. The defaults were recommended based on:

- Data collected from agencies responsible for deploying and maintaining ITS services in Florida. This data was collected using a questionnaire that was developed and distributed to various Florida public sector agencies.
- Estimated quantities in conjunction with statewide pay item unit costs obtained from the FDOT State Estimates Office's unit cost database. [26]
- Previous cost estimates reported in ITS studies. These studies were especially useful in cases where the costs were not available from the first two sources.

Based on the comparison between the collected data and the JPO 2004 unit costs database, dollar amounts were recommended that better reflect the Florida-specific low and high capital costs, operations and maintenance costs, equipment quantity, and life-cycle amortization. To account for the additional costs such as design and CEI in total project costs, 35 percent of the unit deployment costs were added to the capital costs of roadside equipment and communication infrastructure, and 20 percent for other equipment. In order to express the costs in 1995 dollars as required in IDAS, the inflation rate was calculated based on three different indices, that is, Consumer Price Indexes, Implicit Price Index, and FDOT Price Index. Furthermore, an annual procedure to update and customize the IDAS cost database was also provided in this work.

Table 4-1 shows the Florida-specific unit costs derived in the above-mentioned study, as compared with the unit costs presented in the 2004 USDOT database and the 2006 adjusted and unadjusted costs. The 2006 USDOT cost database took into consideration the cost parameters identified in the Florida study mentioned above.

[25] Hadi, M. and S. Prasoon, Technical Memorandum No. 4: "ITS Deployment Analysis System (IDAS) Customization– Florida-Specific Intelligent Transportation System Deployment Costs," Version 2, FDOT Contract No. C 7772, Tallahassee, FL, August 2004.

[26] Available online at http://www2.dot.state.fl.us/SpecificationsEstimates/Estimates/BasisofEstimates/BOEManual/BOEOnline.aspx

Table 4-1 Recommended Florida-Specific Intelligent Transportation System Costs Compared to Costs Obtained from Existing Databases

SUBSYSTEM / UNIT COST ELEMENTS	Deployment Location	USDOT ITS UNIT COSTS (2004)				USDOT ITS UNIT COSTS (2006)				IDAS DATABASE				RECOMMENDED FLORIDA COSTS			
		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Automatic Detection System																	
Call Boxes	Per location		5.9	0.714	0.714	4 (4)	6.8 (6.7)	0.25 (0.25)	0.58 (0.58)					8.6	10	0.18	0.48
Inductive Loop Surveillance (per two lanes) for Corridors	Per two lanes	3	8	0.5	0.8	3 (3)	8 (7)	0.4 (0.4)	0.6 (0.6)	3	16	1	4	3.7	6.8	0.175	1
Inductive Loop Surveillance at Intersections	Per intersection	9	16	1	1.6	8.6 (8.6)	15.3 (15.3)	0.9 (0.9)	1.4 (1.4)					9.5	16.2	0.6	0.8
Machine Vision Sensors for Corridors	One sensor (both directions)	21.7	29	0.2	0.4	21.7 (20.8)	29 (29)	0.2 (0.2)	0.4 (0.4)					35.1	45.0	0.4	0.7
Machine Vision Sensors at Intersections	Per intersection	20	25.7		0.2	16 (16)	25.5 (25.5)	0.2 (0.2)	1 (1)					21.4	27.0	0.25	0.5
Passive Acoustic Sensors for Corridors	Per direction	3.7	8	0.2	0.4	3.7 (3.5)	8 (7.5)	0.2 (0.2)	0.4 (0.3)					0.0	0.0		
Passive Acoustic Sensors at Intersections	Per intersection	5	15	0.2	0.4	5 (5)	15 (14)	0.2 (0.2)	0.4 (0.4)					0.0	0.0		
RTMS for Corridors	Per direction	3.3	6		0.1	9 (9)	13 (13)	0.1 (0.1)	0.58 (0.58)					5.6	12.9	0.2	0.4
RTMS at Intersections	Per intersection		18		0.1	18 (17)	18 (17)	0.1 (0.1)	0.1 (0.1)					0.0	0.0		
CCTV Video Cameras	Per location	7.5	17	1.5	2.4	9 (9)	19 (19)	1 (1)	2.3 (2.3)	7.5	17	1.5	2.4	18.9	24.3	1.5	4

- FHWA ITS unit costs (2006): the unit costs without the brackets are unadjusted, and the costs with brackets are expressed in 2005 dollar.

Table 4-1
(continued)

SUBSYSTEM / UNIT COST ELEMENTS	Deployment Location	USDOT ITS UNIT COSTS (2004)				USDOT ITS UNIT COSTS (2006)				IDAS DATABASE				RECOMMENDED FLORIDA COSTS			
		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Automatic Detection System (CONTINUED)																	
CCTV Video Camera Towers	Per location		12			4 (4)	12 (12)			1	12	0	0	6.8	16.2		
ESSs (Weather Stations)	Per location	10	50	1.9	4.1	29 (29)	48 (48)	1.9 (1.9)	4 (4)					33.8	67.5	2	4
Roadside Control (RS-C)																	
Linked Signal System LAN	Per system	40	70	0.4	0.8	23 (23)	54 (54)	0.4 (0.3)	0.8 (0.6)	40	70	0.4	0.8	360	558	3	5
Signal Controller Upgrades for Signal Controls	Per controller	2.5	10	0.2	0.5	2.5 (2.4)	6 (6)	0.2 (0.2)	0.4 (0.4)	2.5	10	0.2	0.5	3.0	17		
Signal Controllers	Per controller	11	17.5	0.2	0.9	8 (8)	14 (14)	0.2 (0.2)	0.5 (0.5)								
Traffic Signals	Per signal	95	115	2.4	3	95 (88)	115 (107)	2.4 (2.1)	3 (2.7)								
Signal Preemption Receivers	Per intersection	2	8	0.05	0.2	2 (2)	6 (6)	0.04 (0.04)	0.2 (0.2)	2	8	0.05	0.2	5.4	10.8	0.15	0.3
Signal Controller Upgrades for Signal Preemption	Per controller	2	5			2 (2)	4 (4)			2	5						
Ramp Meters	Per direction	30	50	1.5	3.5	25 (24)	50 (48)	1.2 (1.1)	2.8 (2.7)	30	50	1.5	3.5	33.8	84.4	1	2
Software for Lane Control	Per center	25	50	2.5	5	25 (24)	50 (48)	2.5 (2)	5 (5)	6	9			270.0	405.0	10	15
Lane Control Gates	Per location	100	150	2	3	100 (77)	150 (115)	2 (1.5)	3 (2)	100	150	2	3	90.0	135.0	3	5
Fixed-Lane Signals	Per location	6	8	0.6	0.8	6 (5)	8 (6)	0.6 (0.5)	0.8 (0.6)	6	8	0.6	0.8				

Table 4-1
(continued)

SUBSYSTEM / UNIT COST ELEMENTS	Deployment Location	USDOT ITS UNIT COSTS (2004)				USDOT ITS UNIT COSTS (2006)				IDAS DATABASE				RECOMMENDED FLORIDA COSTS			
		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Roadside Information (RS-I)																	
Roadside Message Signs	Per direction	50	75	2.5	3.75	50 (38)	75 (57)	2.5 (2)	3.75 (3)	50	75	2.5	3.75				
Roadside Information (RS-I) (CONTINUED)																	
Wire line-to-Roadside Message Signs	Per direction	6	9			6 (5)	9 (8)			6	9	0	0				
VMS	Per direction	48	120	2.4	6	47 (47)	117 (117)	2.3 (2.3)	6 (6)	48	120	2.4	6	47.3	175.5	5	16
VMS Towers	Per direction	25	125			25 (25)	120 (120)			25	125	0	5	33.8	168.8		
Dynamic Trailblazers	Per location													23.0	67.5	1	4
HAR	Per location	16	32	0.6	1	15 (15)	35 (35)	0.6 (0.6)	1 (1)	16	32	0.6	1	56.7	62.1	2.1	2.5
HAR Signs	Per direction	5		0.25		5 (5)	9 (9)	0.25 (0.25)	0.25 (0.25)					12.2	20.9	0.5	1
Roadside Probe Beacons	Per direction	5	8	0.5	0.8	5 (5)	8 (7)	0.5 (0.5)	0.8 (0.7)	5	8	0.5	0.8	40.5	43.2	0.4	0.8
Roadside Rail Crossing (R-RC)																	
Rail Crossing 4-Quad Gates and Signals	Per location	115	130	4.25	4.85	115 (88)	130 (100)	4.25 (3.3)	4.85 (3.7)	115	130	4.25	4.85				
Rail Crossing Train Detectors	Per location	16	21.5	0.77	1.03	16 (12)	21.5 (16)	0.77 (0.6)	1.03 (0.79)	16	21.5	0.77	1.03				
Rail Crossing Controllers	Per location	8	10	0.4	0.5	8 (6)	10 (8)	0.4 (0.3)	0.5 (0.4)	8	10	0.4	0.5	9.0	12.6	0.3	0.5
Rail Crossing Pedestrian Warning Signals and Gates	Per location	10	15	0.2	0.3	10 (8)	15 (11)	0.2 (0.2)	0.3 (0.2)	10	15	0.2	0.3	16.1	49.5		
Rail Crossing Trapped Vehicle Detectors	Per location	25	30	1.25	1.5	25 (19)	30 (23)	1.25 (1)	1.5 (1.1)	25	30	1.25	1.5				
Traffic Management Centers (TMC)																	

Table 4-1
(continued)

SUBSYSTEM / UNIT COST ELEMENTS	Deployment Location	USDOT ITS UNIT COSTS (2004)				USDOT ITS UNIT COSTS (2006)				IDAS DATABASE				RECOMMENDED FLORIDA COSTS			
		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Basic Facilities, Communications for Large Area (>750,000 population)	Per center	4,000	4,000	400	600	3,500 (4,060)	8,000 (9,279)	350 (406)	1,200 (1,392)	4,000	4,000	400	600	5,800	7,200	400	500
Traffic Management Centers (TMC) (CONTINUED)																	
Basic Facilities, Communications for Medium Area	Per center	3200	3200	400	480	3,200 (4,050)	3,200 (4,050)	400 (506)	480 (608)	3200	3200	400	480	3,200	4,200	200	400
Basic Facilities, Communications for Small Area (<250,000 population)	Per center	2800	2800	400	420	2,800 (3,544)	2,800 (3,544)	400 (506)	420 (532)	2800	2800	400	420	2,800	2,800	100	200
Hardware for Surveillance, Incident Detection and Response, and Information Dissemination	Per center					180.8 (170.4)	234.6 (220.8)	9.05 (8.53)	11.65 (10.97)	224.4	297.6	11.22	14.88	100	200	40	50
Software/Integration for Surveillance, Incident Detection and Response, and Information Dissemination	Per center					481.5 (449.1)	588.5 (548.9)			481.5	588.5			200	500	25	50
Video Monitors, Wall for Incident Detection	Per center					57 (48)	103 (87)	3 (3)	5 (4)	40.5	49.5	2.025	2.475	100	350	35	55
Labor for Incident Detection and Response, and Information Dissemination	Per center							810 (939)	990 (1,148)			810	990			300	1,200
Transit Center Software Integration	Per transit vehicle	815	1,720	6	12	775 (775)	1,636 (1,636)	6 (6)	12 (11)	815	1,720	6	12	300	1,500	6	12

Table 4-1
(continued)

SUBSYSTEM / UNIT COST ELEMENTS	Deployment Location	USDOT ITS UNIT COSTS (2004)				USDOT ITS UNIT COSTS (2006)				IDAS DATABASE				RECOMMENDED FLORIDA COSTS			
		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Advanced Public Transit Systems (APTS) – On-Board, Remote, and Center																	
GPS/DGPS for Vehicle Location	Per transit vehicle	0.5	0.8	0.01	0.016	0.5 (0.5)	2 (2)	0.01 (0.01)	0.04 (0.038)	0.5	0.8	0.01	0.016	10	15	0.1	0.15
Advanced Public Transit Systems (APTS) – On-Board, Remote, and Center (CONTINUED)																	
Signal Preemption Processor	Per transit vehicle	0.3	0.6	0.003	0.006	0.3 (0.2)	0.6 (0.5)	0.006 (0.005)	0.01 (0.008)	0.3	0.6	0.003	0.006	0.5	2.2	0.006	0.022
Security Package (CCTV, Hot Button)	Per transit vehicle	4.2	5.3	0.21	0.26	3.2 (3.2)	6.2 (6)	0.21 (0.16)	0.265 (0.2)	4.2	5.3	0.21	0.26	6	12	0.2	0.4
Electronic Fare Box	Per transit vehicle	0.8	1.5	0.04	0.075	0.8 (0.6)	1.5 (1.1)	0.04 (0.03)	0.075 (0.06)	0.8	1.5	0.04	0.075	11.4	13.2	0.2	0.4
APC	Per transit vehicle					0.96 (0.96)	9.6 (9.6)							10	15	0.2	0.4
CCTV Camera at Remote Location	Per location	4	5	0.08	0.10	2 (2)	5 (5)	0.1 (0.1)	0.24 (0.24)	4	5	0.08	0.10	15	25	0.5	1.0
Electronic Toll Collection (ETC)																	
Electronic Toll Equipment (On-Board)	Per vehicle	0.04				0.04 (0.03)	0.1 (0.1)			0.04	0.1			0.03	0.05		
Toll Administration Hardware	Per plaza	10	15	0	0.02	6.4 (5.9)	9.6 (8.8)	0.32 (0.29)	0.48 (0.44)	10	15	0	0.02	100	150	5	7
Toll Administration Software	Per plaza	40	80	4	8	40 (38)	80 (76)	4 (3.8)	8 (7.6)	40	80	4	8	400	600	20	30
ETC Reader	Per lane	2	5	0.2	0.5	2 (2)	5 (5)	0.2 (0.2)	0.5 (0.5)	2	5	0.2	0.5	8	12	0.4	0.6
High Speed Camera	Per lane	5	10	0.5	1.0	7 (7)	10 (10)	0.5 (0.4)	1.0 (0.8)	5	10	0.5	1.0	6	10	0.5	1.0
ETC Hardware/ Software at Toll Plaza	Per plaza	5	10	5	10	5 (5)	10 (10)			5	10			150	250	7	10
ETC Toll Plaza Structure	Per plaza	10	15	0	0.02	10 (13)	15 (19)			10	15	0	0.02	13	20	0.1	0.2
Classification/Detection														10	14	1	1.5

Table 4-1
(continued)

SUBSYSTEM / UNIT COST ELEMENTS	Deployment Location	USDOT ITS UNIT COSTS (2004)				USDOT ITS UNIT COSTS (2006)				IDAS DATABASE				RECOMMENDED FLORIDA COSTS			
		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Commercial Vehicle Administration Software, Integration	Per center	200	220	4	4.4					200	220	4	4.4	500	1,000	10	20
Commercial Vehicle Operations (CVO)																	
Software Upgrade for Electronic Credential Purchasing and Management	Per center	60	140	1.2	2.8					60	140	1.2	2.8	500	1,000	10	20
Software Upgrade for Interagency Information Exchange	Per center	20	40	0.4	0.8					20	40	0.4	0.8	300	1,500	10	20
Software Upgrade for Safety Administration	Per center	40	80	40	80					40	80	40	80	400	600	10	20
DS0 Communication Lines	Per line	0.5	1	0.6	1.2	0.5 (0.5)	1 (0.9)	0.6 (0.6)	1.2 (1.2)	0.5	1	0.6	1.2	0.8	1.5	1.5	2
Communications Subsystem																	
DS1 Communication Lines	Per line	0.5	1	4.8	8.4	0.5 (0.5)	1 (0.9)	4.8 (4.8)	9.6 (9.6)	0.5	1	4.8	8.4	0.8	1.5	5.6	10
DS3 Communication Lines	Per line	3	5	24	72	3 (2.7)	5 (4.6)	24 (22)	72 (67)	3	5	24	72	3	5	25	132
Direct-Bury, Armor-Encased Fiber Cables	Per mile		60		0.02												
Conduit Design and Installation per Mile for Corridors	Per mile		65		0.02	50 (50)	75 (75)	3 (3)	3 (3)					108			
Fiber Optic Cable Installation per Mile	Per mile		20		.02	20 (20)	52 (52)	1 (1)	2.5 (2.5)					22	34		
Under Pavement Bore	Per location													2	4		

Table 4-1
(continued)

SUBSYSTEM / UNIT COST ELEMENTS	Deployment Location	USDOT ITS UNIT COSTS (2004)				USDOT ITS UNIT COSTS (2006)				IDAS DATABASE				RECOMMENDED FLORIDA COSTS			
		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)		Capital Cost ($K)		O&M Cost ($K/Year)	
		Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Ethernet Core Switch	Per location														140		
Ethernet Hub/Routing Switch	Per location													3	10		
Communications Subsystem (CONTINUED)																	
Ethernet Edge Switch	Per location													1	4		

4.3 ITS Dollar Values

Table 4-2 presents a list of the parameters used by the IDAS to convert ITS impacts to dollar values. Hadi et al.[27] examined the parameters IDAS uses to convert various ITS impacts to dollar values and recommended changes to these parameters to reflect the values used in Florida. The following is a summary of the changes made to IDAS defaults in accordance with the recommendations:

- The value of travel time for a single-occupancy automobile was changed from $9.63 to $5.15 and for multiple-occupancy autos from $9.63 to $6.70 (assuming 1.3 vehicle occupancy).
- For commercial vehicles, the travel time value was changed from $16.96 to $50.80.
- For buses, the travel time value was changed from $8.90 to $30.00, assuming 14 passengers and a driver in each bus and the value of travel time for passengers as one-third the wage rate for work or commuting trips.
- The vehicle operating cost per vehicle-mile (excluding fuel cost) was changed from $0.034 for autos, $0.245 for commercial trucks, and $0.0 for buses to $0.25 for commercial vehicles and transit vehicles and $0.2 for personal autos.
- The values of crash costs were changed from $2,726,350 for fatal crashes, $59,718 for injury crashes, and $3,322 for Property Damage Only (PDO) crashes to $2,935,000 for fatal crashes, $72,000 for injury crashes, and $1,776 for PDO crashes.
- The dollar values associated with travel-time reliability were calculated in IDAS as 3 multiplied by the travel-time dollar values. The travel-time reliability dollar values were adjusted to reflect the changes made to the travel-time dollar values as discussed above.

The modifications to the dollar values listed above were entered in the IDAS alternative comparison modules and were set as the defaults. These values will be examined further in subsequent chapters.

[27] Hadi, M.A., D. Quigley, P. Sinha, and A. Krishnamurthy, "Intelligent Transportation Systems Deployment Analysis System Customization," Final Report Prepared for the FDOT by PBSJ, Inc., Tallahassee, FL, October 27, 2005.

Table 4-2 The Benefit Dollar Values Used in IDAS

In-vehicle Value of Time per Hour	
Commercial Truck	\$20.80
All Other Modes	\$8.50
Travel Time Reliability Value per Person Hour	
Commercial Truck	\$62.40
All Other Modes	\$25.50
Cost of Fuel per Gallon	
Commercial Truck, Bus	\$1.15
Autos	\$1.21
Non-fuel Vehicle Operating Costs per Mile	
Commercial Truck	\$0.10
Auto	\$0.03
Emissions Cost per Ton – All Modes	
Hydrocarbons	\$1,774.00
Nitrous Oxides	\$3,731.00
Carbon Monoxide	\$3,889.00
Particulates (PM_{10})	\$11,066.00
Carbon Dioxide	\$3.56
Accident Costs per Fatality – All Modes	
Internal Cost	\$2,317,398.00
External Cost	\$408,952.00
Accident Costs per Injury – All Modes	
Internal Cost	\$50,760.00
External Cost	\$8,958.00
Accident Cost per Property Damage-only Accident	
Internal Cost	\$2,824.00
External Cost	\$498.00

5 General Requirements and Design

This chapter details the general requirements of the ITS evaluation tool developed as part of this project to support the evaluation of ITS for planning purposes. These requirements address the different types of evaluated ITS deployment, evaluated impacts/performance measures, supporting modules, and other general evaluation requirements. Requirements that are specific to individual ITS component evaluation modules are shown in Sections 6 to 16. This document refers to the sketch planning tool developed here as “the Tool.” The requirements presented in this document were reviewed and fine-tuned in a workshop conducted during the early stages of this project.

5.1 General Requirements

5.1.1 Time-of-Day Analysis Requirements

- The benefit-cost analysis shall be based on the time-of-day period analysis.

- The benefits for each analysis time period shall be calculated separately and the total benefits shall be calculated as the sum of the benefits over all the analyzed time periods.

- When conducting the analysis utilizing regional travel demand models that are based on daily traffic data, period-specific multiplication factors shall be utilized to convert the daily link volumes to analysis period volumes, if required by the methodology for the specific deployment under consideration. The resulting peak period demands shall be used in the benefit-cost analysis.

    - The Tool shall include default period specific factors to convert daily link traffic demand to period-specific traffic for each direction of traffic and each analysis period

    - The user shall be able to modify the default time-of-day factors based on local conditions.

Analysis: The default factors will be derived on data from Broward County state roads. Users should be encouraged to base their values on local conditions.

- When conducting the analysis utilizing regional travel demand models that are based on peak period, the period-specific O-D matrix and/or period-specific link volume as obtained from the regional model shall be used in the analysis, depending on the methodology used for the specific ITS deployment under consideration.

- If additional periods are to be analyzed but data are not available for a time-of-day demand model, multiplication factors of the peak volume traffic shall be used to estimate the demands for these periods based on daily traffic data.

5.1.2 Performance Measures

- The Tool shall produce the benefits of ITS deployment quantified in all or some of the following performance measures, depending on the type of ITS deployment:
  - Vehicle miles of travel (VMT)
  - Vehicle hours of travel (VHT)
  - Average speed
  - Number of accidents
    - Fatality
    - Injury
    - Property damage only
  - Fuel Consumption (gallons)
  - Monetary benefits to users and/or agency, as appropriate
  - Emissions
    - Hydrocarbon
    - Carbon monoxide
    - Oxides of Nitrogen

- The developed tool shall support the economic approach of evaluating ITS to provide a financial justification for investing in ITS.
  - The tool shall calculate the benefit/cost ratio of alternative ITS deployments.
  - The Tool shall include default values to convert various performance measures to dollar values for use in the benefit-cost analysis. The Tool shall allow the user to modify the default parameters that convert the benefits to dollar values.

- The Tool shall estimate the costs of ITS deployments.
  - The cost information shall include the number and types of equipment required for each type of evaluated ITS deployment.
  - The cost information shall include initial cost, operation and maintenance cost, estimated interest rate, and life-time equipment amortization.

 - The cost information shall include low, high, and average values for each item.
 - The cost estimates shall be based on per units of deployments (e.g., per mile of deployments, per bus per number of intersections).
 - The study team shall distribute the identified cost information to the FDOT ITS districts, selected signal agencies, and selected transit agencies to determine if any modification to the cost database is needed.

- The tool shall include ITS impact parameters that allow the calculation of ITS deployment benefits
 - The ITS impact parameters shall be derived based on a review of the results from previous evaluation studies, USDOT JPO benefit database, and the values used in existing ITS sketch planning tools.
 - The user shall be able to change the default ITS impact parameters
 - The default and user input values for the ITS impact parameters shall include minimum and maximum values.
- The benefit-cost evaluation procedures shall allow users to input additional cost components calculated external to the model. The evaluation procedures shall account for these components, and they will be used in combination with the measures quantified using IDAS in the overall project ranking process.

5.1.3 Supporting Module Requirements

- When needed, the Tool shall utilize the trip distribution module, assignment module, mode choice module, and demand-speed relationships developed for the region and used in the validated FSUTMS regional demand forecasting models.
- The Tool shall include a module to estimate the environmental impacts in terms of pollution due to traffic emission with and without ITS deployments.
 - The emission module shall estimate the impacts of traffic stream characteristics on the CO, NOx, and HC emissions.
 - The emission module shall be based on the Mobile6 modules developed for the Florida regions.
 - The emission module shall take conditions including idling in queues during incidents into consideration.

- The Tool shall include a module to estimate the fuel consumption based on the characteristics of the traffic stream.
    - The selected fuel consumption model shall be based on a review of those used in the sketch planning tools and those used in the literature.
    - The default module shall be the IDAS module modified to eliminate unrealistic increase in fuel consumption with increased speed.
- The Tool shall include a module to estimate the safety with and without ITS deployments.
    - The safety module shall provide estimation of property damage only, injury, and fatality crashes as a function of volume to capacity (V/C) ratio and vehicle-miles traveled.
    - The Florida-Specific IDAS safety module developed in a previous FDOT project shall be used as the default safety module in the Tool.
- The user shall have the ability to override the default emission, fuel consumption, and safety modules.
    - The user shall document and justify any override of the default values.

5.1.4 Evaluated Deployments

- The evaluated ITS deployments shall include regional, freeway, arterial, and transit deployment categories
- The evaluated regional deployment shall include
    - Regional travel information systems
- The evaluated freeway deployments shall include
    - Ramp metering
    - Incident management systems
    - Highway advisory radio (HAR) and dynamic message signs (DMS)
    - Smart work zones
    - Road weather information systems (RWIS)
    - Managed lanes
- The evaluated arterial deployments shall include
    - Signal control
    - Emergency vehicle signal priority
    - Transit priority systems
- The evaluated transit deployments shall include

- Monitoring and management of fixed route transit
- Transit information systems
- Transit security systems
- Transit electronic payment systems

5.2 General Design

This section presents the general design of the ITS evaluation tool developed in this study. The design and implementation of individual evaluation of ITS deployments is presented in the sections that discuss these individual evaluations (Sections 6 to 16). The actual code written in the script language of Cube is provided on a CD-ROM that accompanied this report.

5.2.1 Logical Design

This section presents the logical design of the developed tool including a data flow diagram (DFD) as a graphical representation of the processes and the exchange of data between processes. Data flow diagrams represent a useful visualization of the logical design of software in terms of the required processes and interfaces of the tool. The logical design can be used as a basis for the physical design of the system, described in Section 5.2.2.

The data flow diagrams of the developed tool are presented in Figure 5-1 to Figure 5-4. These data flow diagrams were used to communicate what processes must be used and what data must flow between these processes to satisfy the identified requirements for the tool.

The highest level data flow diagram is the Context Diagram, which is sometime referred to as Level 0. The Context Diagram indicates the entities that are not part of the developed Tool but will need to communicate with our Tool, as well as their interfaces with the system. It shows the data that the developed system shares with these other entities and the boundary of the developed system. As indicated in Figure 5-1, the evaluation of benefits and costs require input data from an ITS benefit database, ITS cost database, benefit dollar values, regionally-calibrated FSUTMS modules, and the users of the system.

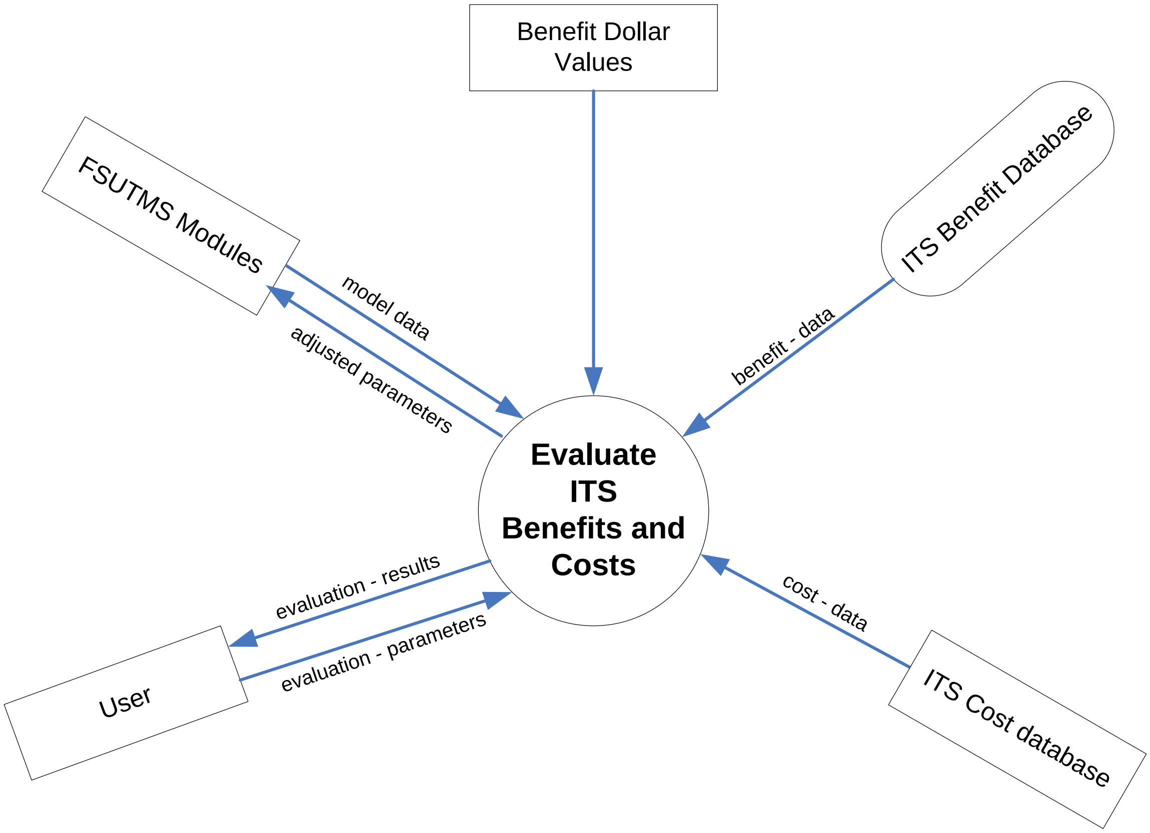


Figure 5-1 Context Diagram – DFD Level 0

Figure 5-2 shows Level 1, which is the DFD level just below the Context Diagram Level. This level shows the highest level processes required for the evaluation of the benefits and costs of ITS. Each of these high level processes is further decomposed into sub-processes. The Evaluate ITS Benefits process in Figure 5-2 is decomposed into four main processes: Evaluate Freeway Management, Evaluate Arterial Management, Evaluate Regional ITS Deployments, and Evaluate Advanced Public Transit Systems. Figure 5-3 shows the Evaluate Freeway Management Process. This process is further decomposed into five processes: Evaluate Incident Management and DMS, Evaluate Smart Work Zone, Evaluate Road Weather Information Systems, Evaluate Ramp Metering, and Evaluate Managed Lanes. Figure 5-4 shows the details of one of these processes "Evaluate Incident Management and DMS." Evaluate Arterial Management is decomposed into Evaluate Signal Control, Evaluate Emergency Preemption, and Evaluate Bus Priority. Currently, Evaluate Regional ITS deployment is only decomposed into Evaluate Advanced Traveler Information Systems. Evaluate Advanced Public Transportation Systems is decomposed into Evaluate Automatic Scheduling and Location, Evaluate Transit Security Systems, Evaluate Transit Electronic Payment Systems, and Evaluate Transit Traveler Information Systems.

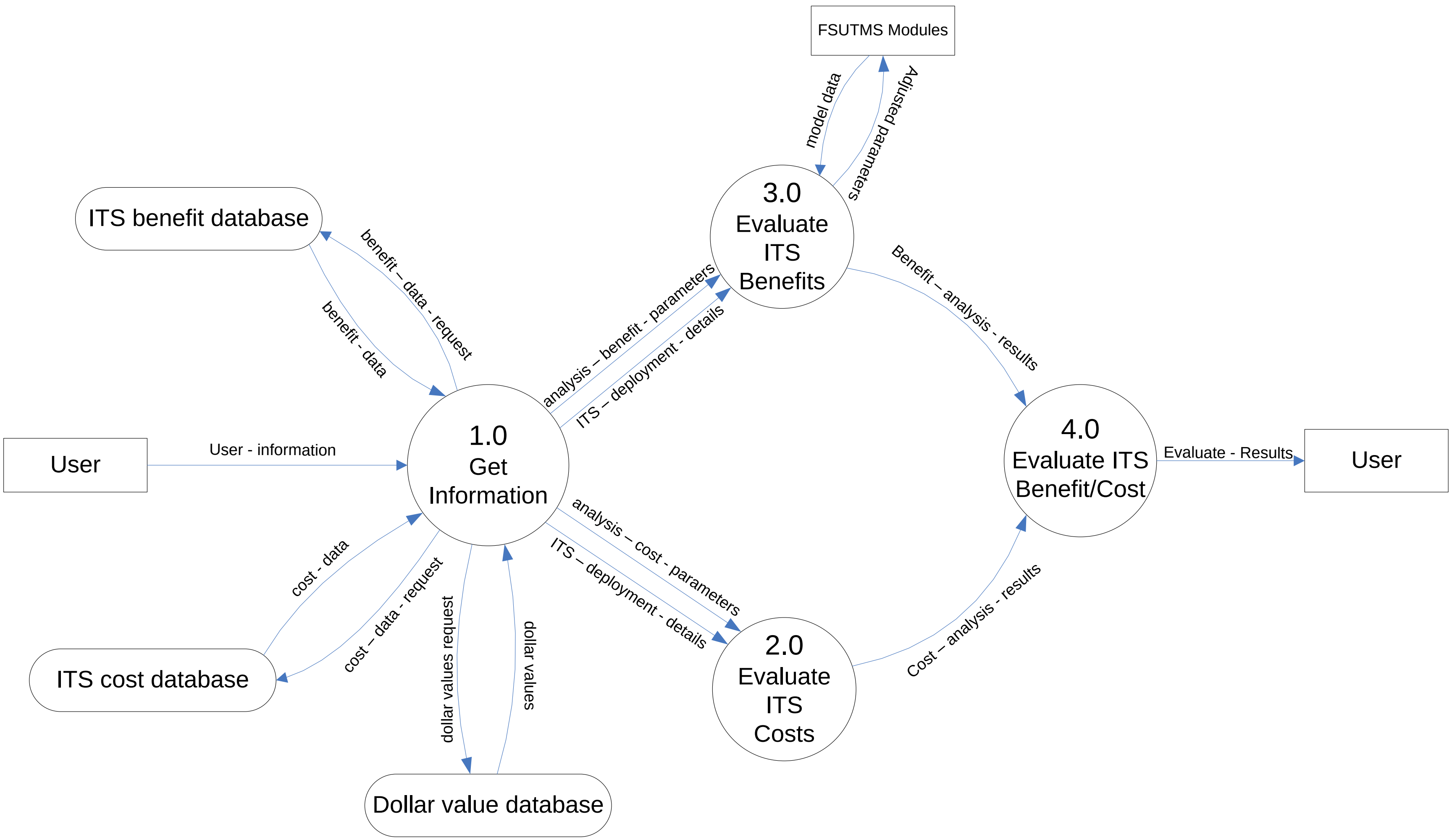


Figure 5-2 DFD Level 1 – Evaluate ITS Benefits and Costs

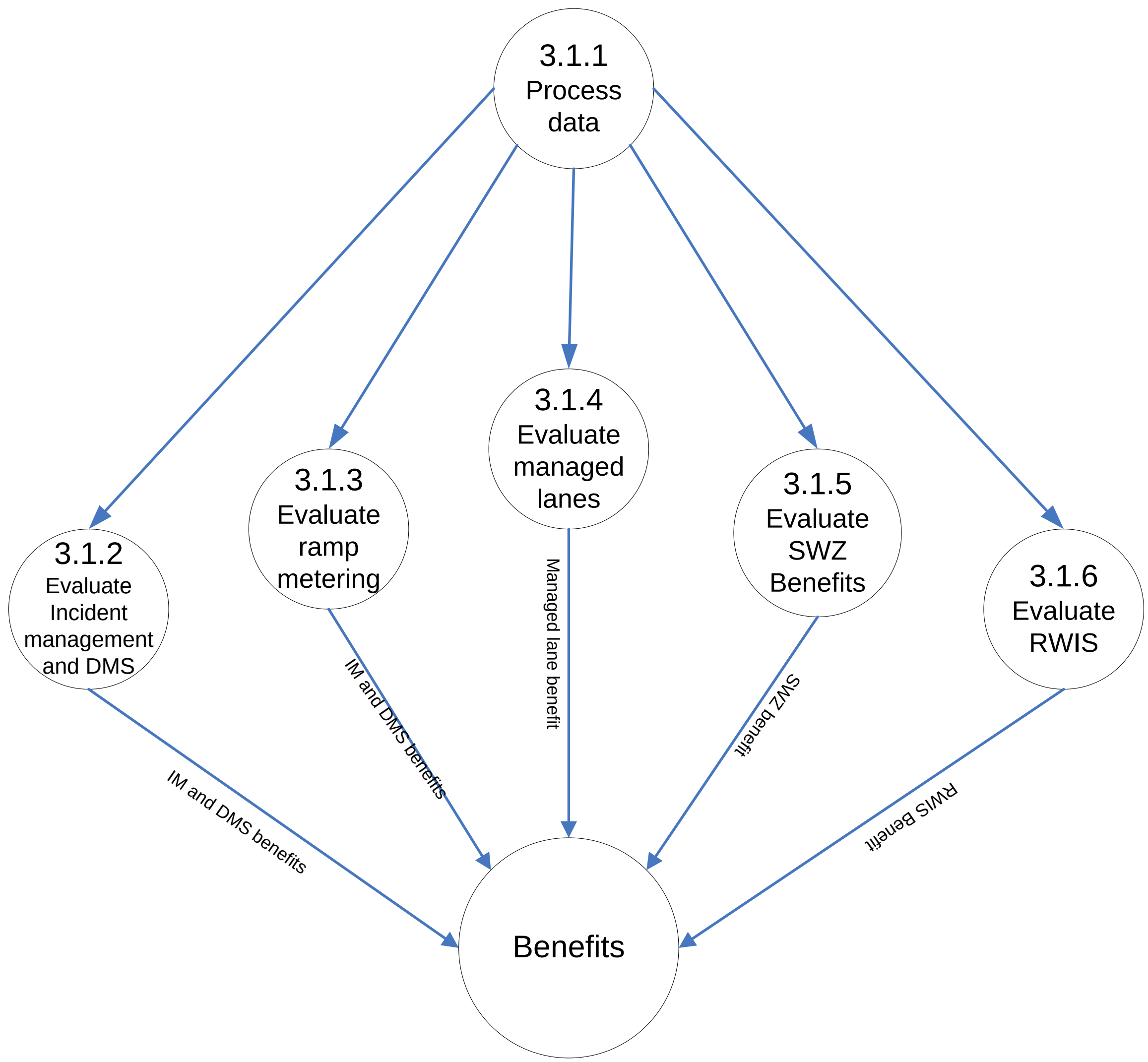


Figure 5-3 Process 3.1. Evaluate Freeway managements

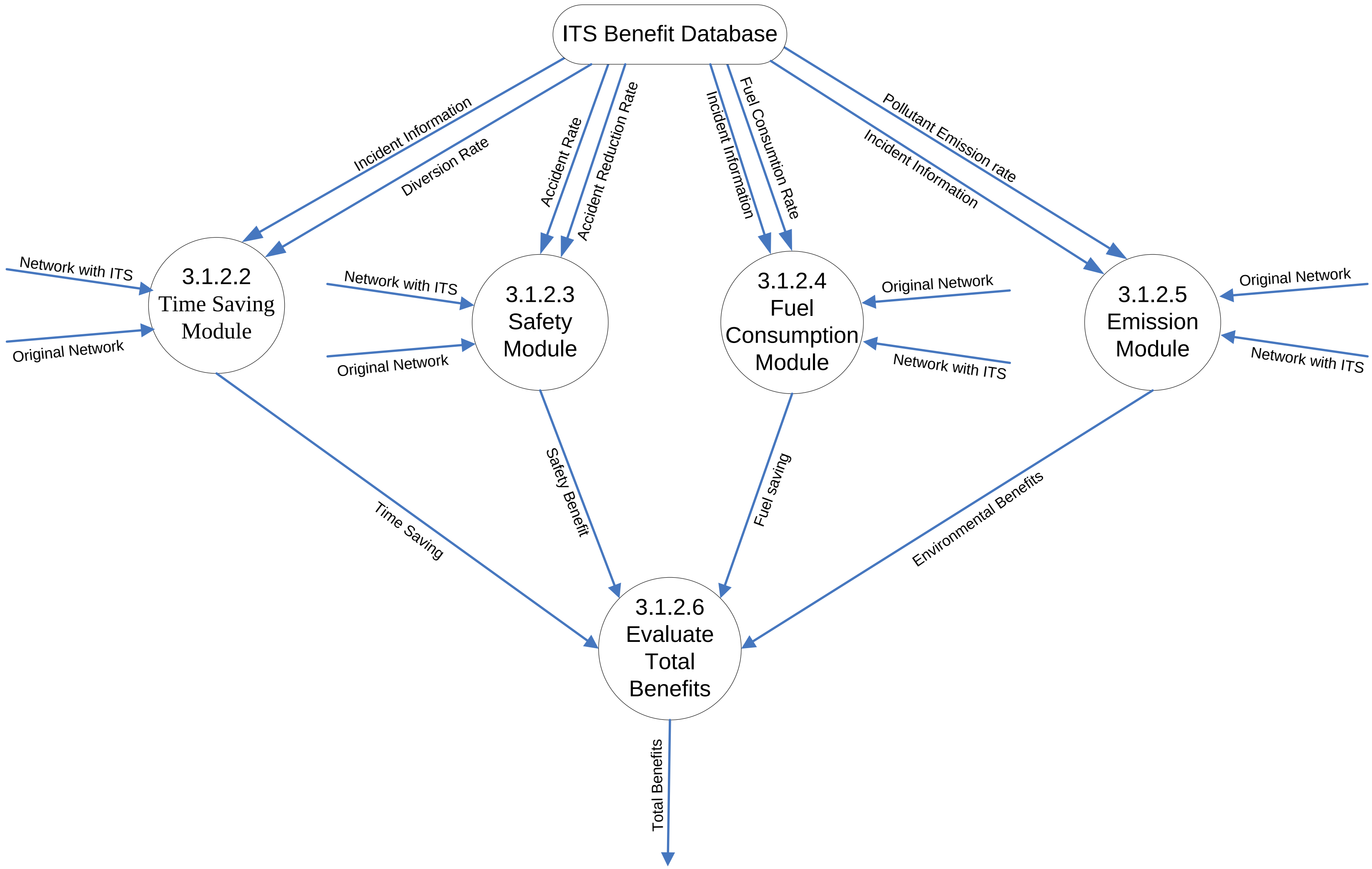


Figure 5-4 Process 3.1.2 Evaluate Incident Management and DMS

5.2.2 Physical Design

The ITS evaluation tool developed in this study is implemented in the FSUTMS/Olympus model using the script language of the Cube software, which is the modeling engine of the FSUTMS. The evaluation tool is coded in Cube as one catalog, called "ITS Evaluation Tool." Each ITS component (such as incident management, ramp metering, advanced traveler information systems, etc.) is organized as one application within this catalog. By selecting the application, the user can identify the ITS deployment that is to be evaluated, as shown in Figure 5-5.

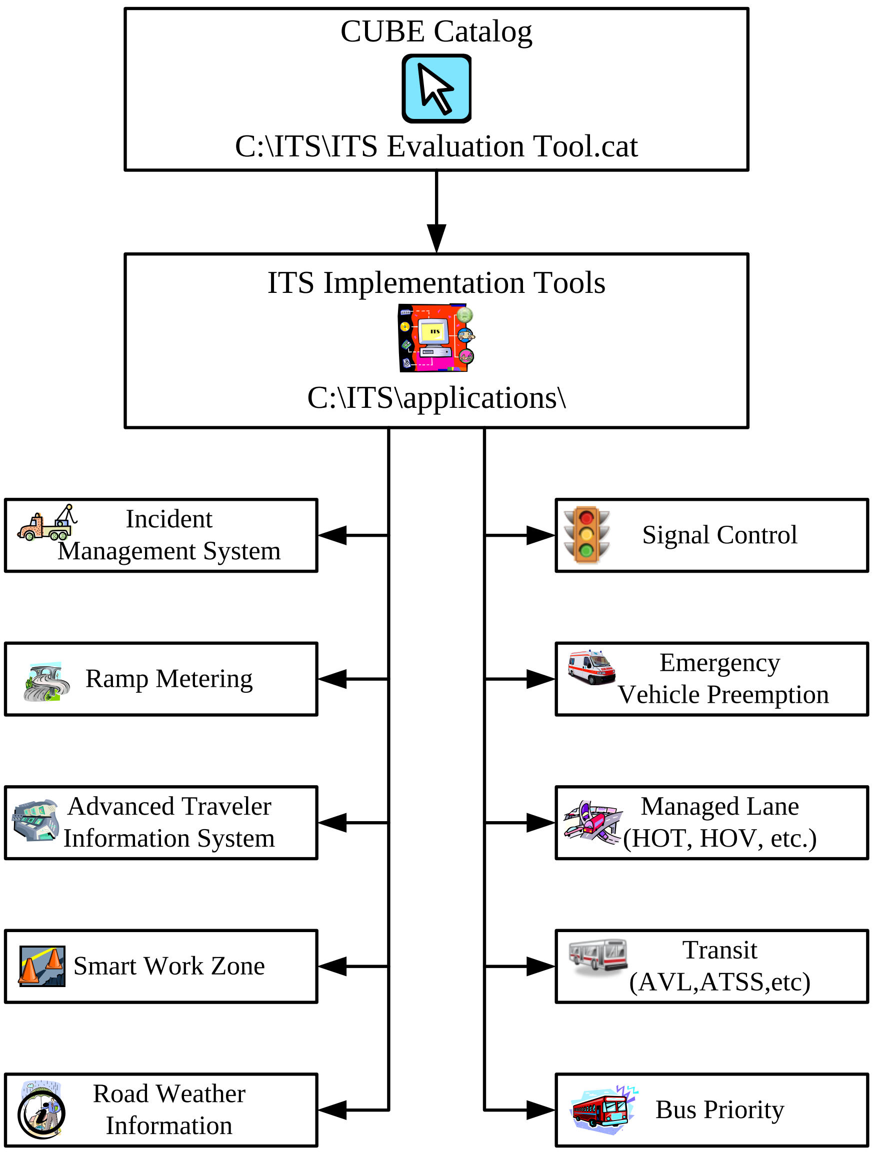


Figure 5-5 Implementation of ITS Evaluation Tools in CUBE Environment

5.2.3 Modeling Structure

An example of the evaluation modeling structure of the developed tool is shown in Figure 5-6. Four modules are shown in
Figure 5-6 as listed below.

- Deployment identification module: This module associates ITS deployments with deployment locations.

- Benefit module: This module provides estimations of the benefits of ITS deployments in terms of travel time, safety, fuel consumption, emissions, and monetary benefits. Figure 5-7 shows the sub-modules that calculate the above benefits. The structure of these sub-modules is further discussed when individual ITS components are discussed in the following chapters.

- Cost module: This module calculates the required equipment, initial and recurrent costs and converting these costs to annual values.

- Benefit/cost ratio module: This module converts all the benefits to dollar values, converts these values to annual values, and then calculates the benefit/cost ratios of ITS deployments.

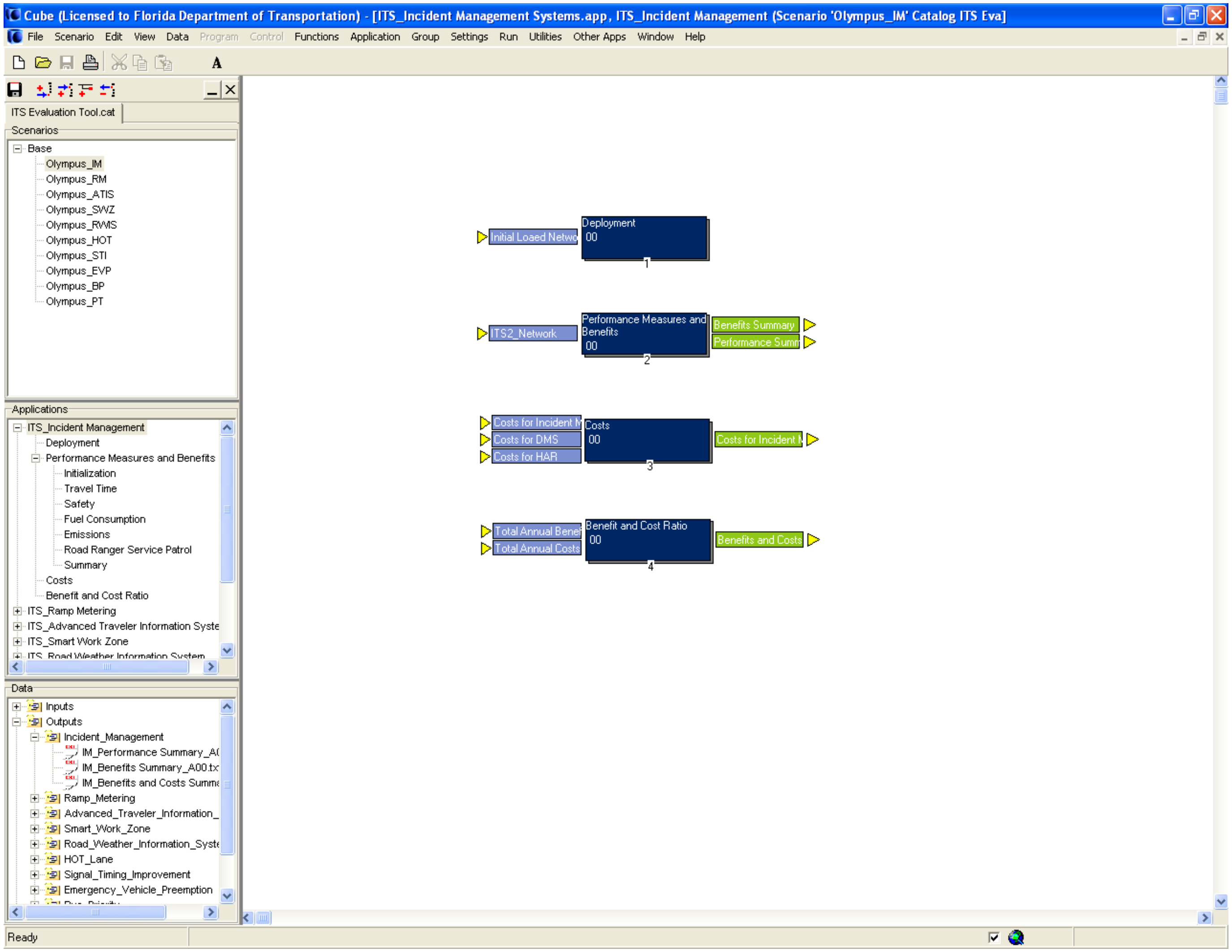


Figure 5-6 the Four Main Modules of the ITS Evaluation Tool

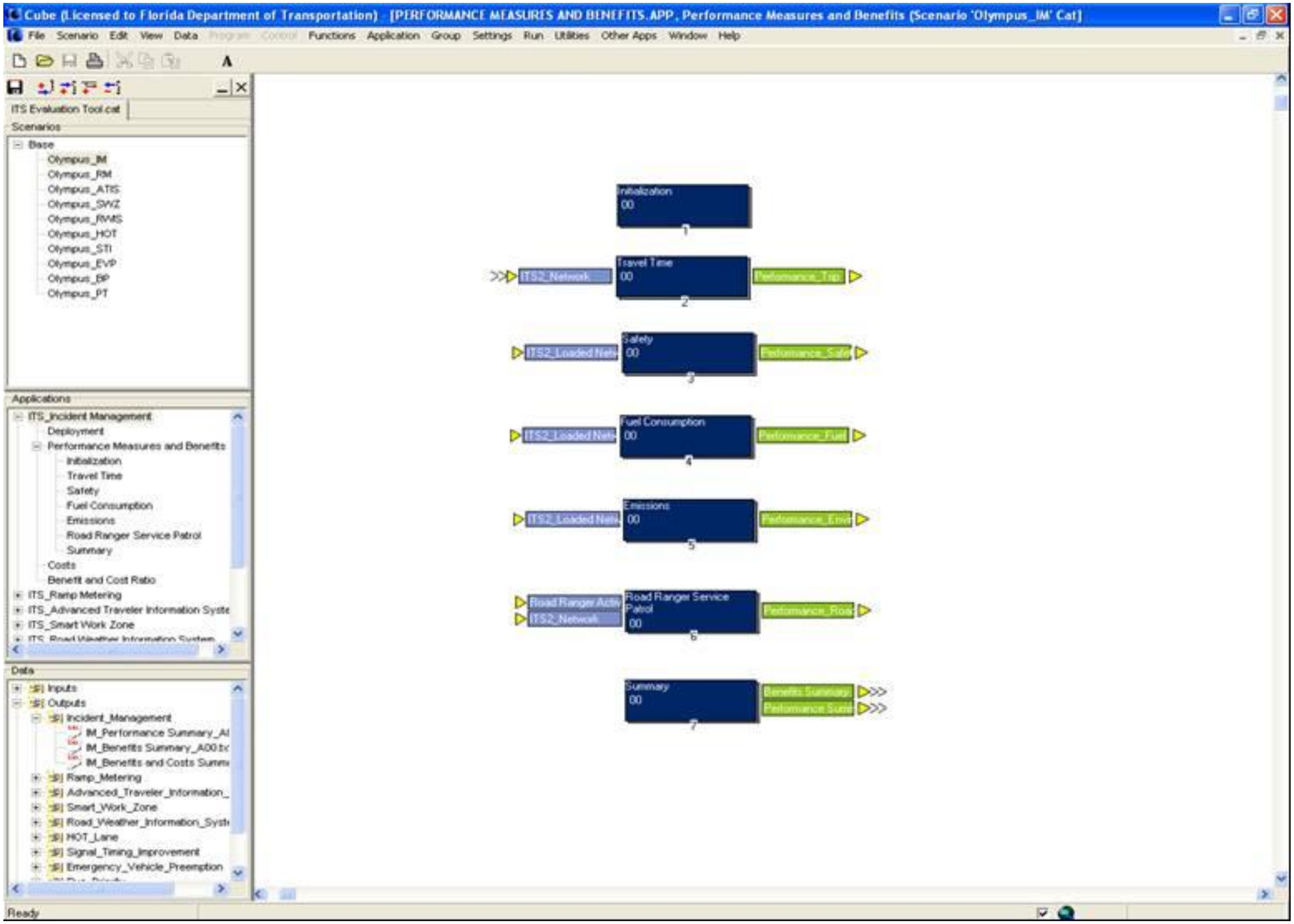


Figure 5-7 the Benefit Evaluation Sub-Modules

5.2.4 User Interface

The parameters required are organized into groups: alternative information, parameters from the demand model, deployment parameters, analysis parameters, impact factors, dollar value, and equipment and costs parameters (see Figure 5-8 and Figure 5-9). Default values are provided for some of the parameters as required; however, the user can modify these default values based on local conditions. As appropriate, the user should also perform sensitivity analysis of the values of those parameters that have uncertainty associated with them.

- Alternative information: This information includes information that identifies the analysis alternative and the working directories as follows:
  - Alternative identification (ID): a letter identifying the analyzed alternative.
  - Modeling year: the year for which the traffic demands are forecasted by the FSUTMS demand model.
  - Location of working directory: this includes an input folder and an output folder. These folders have first to be created under the working directory. The user needs to save all the input files in the input folder. The analysis results will automatically be written to the output folder.

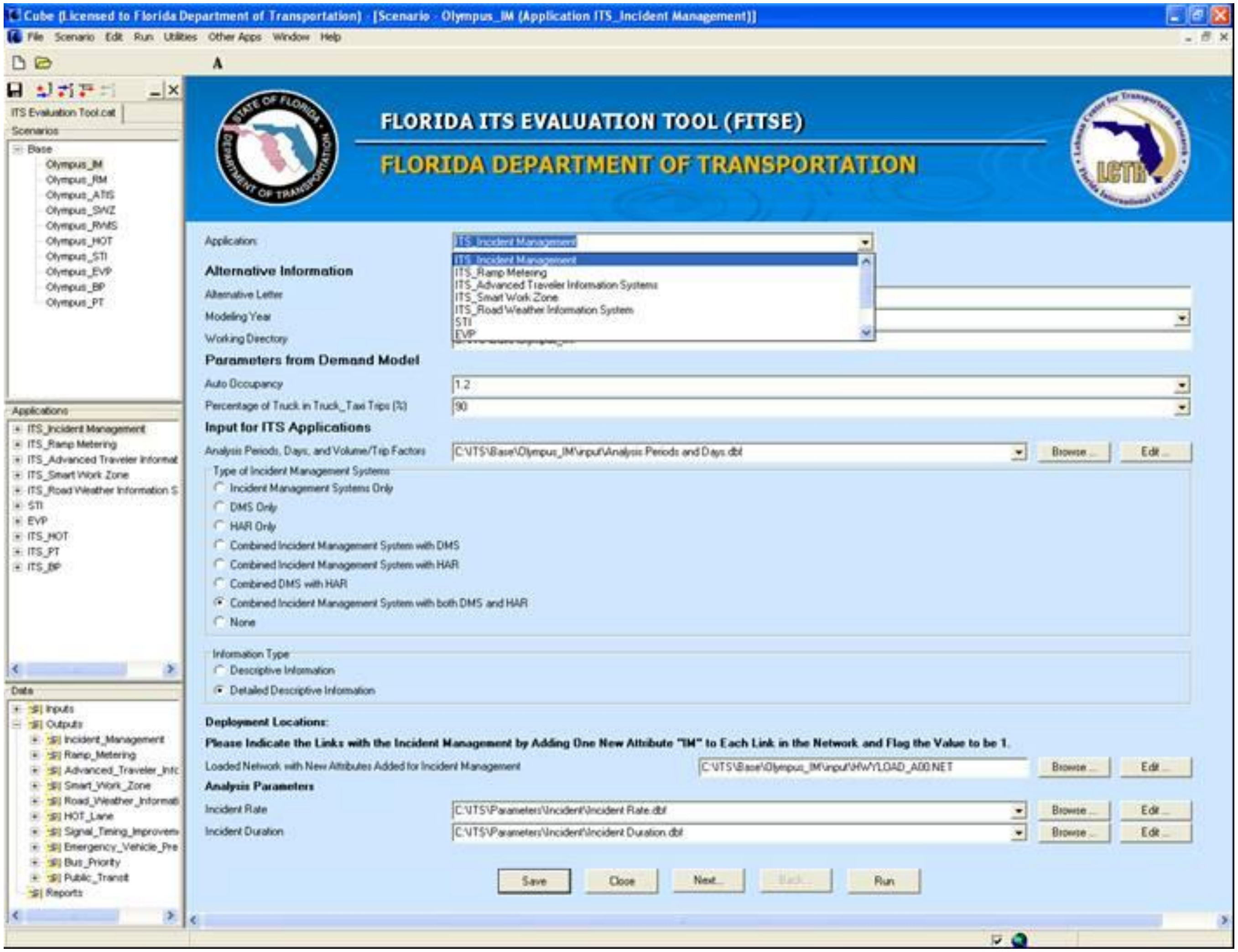


Figure 5-8 Parameter Specifications in the Developed Tool

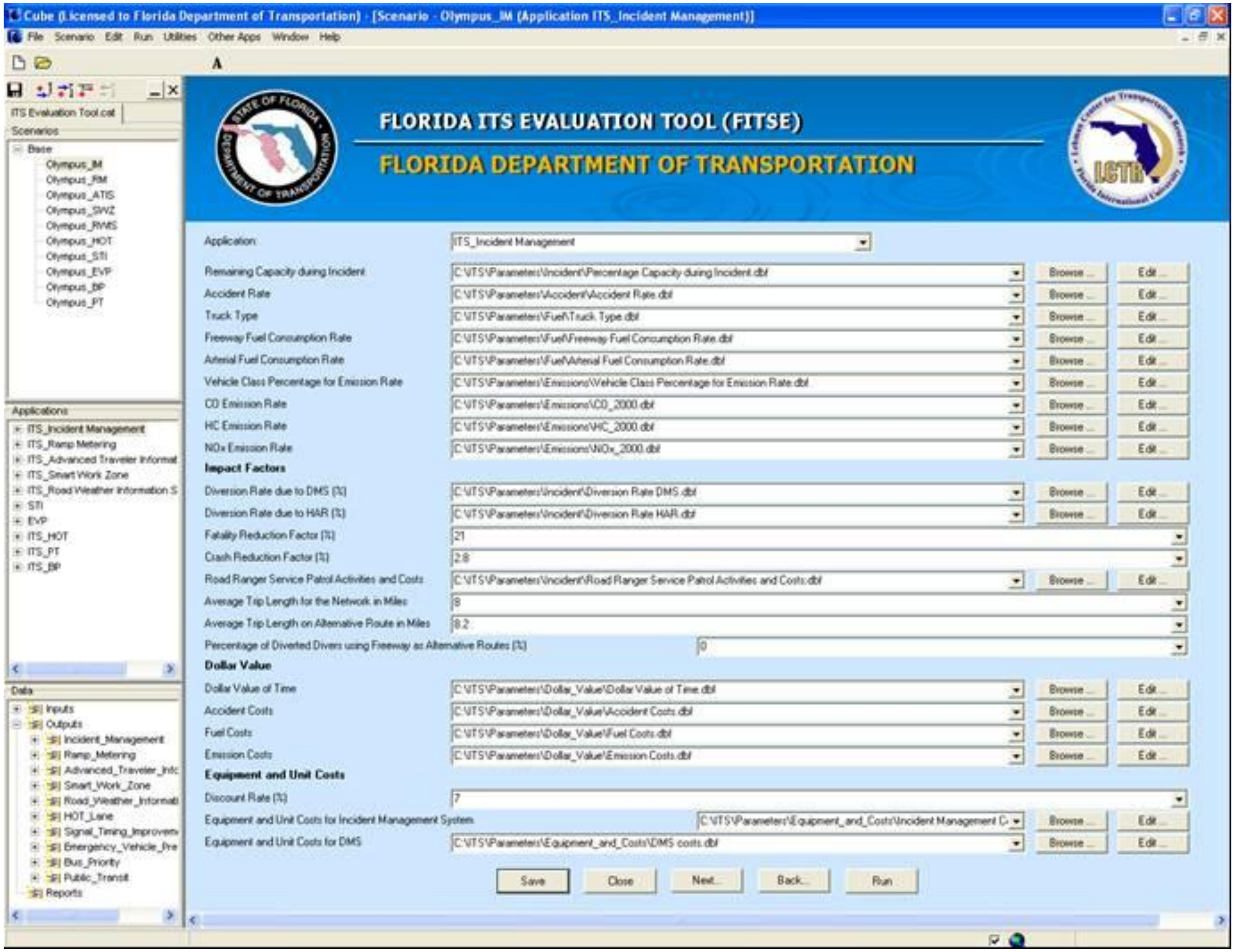


Figure 5-9 Additional Parameter Specifications In The Developed Tool

- Modeling parameters: these parameters include.

    - Auto occupancy: This parameter is obtained from the FSUTMS model files but can be overridden by the user in this field.
    - Percentage of truck trips in TRUCK_TAXI trips: This is a required input to separate the truck and taxi trips since the truck and taxi trips are combined together in the Olympus model. If the truck trip is included as a separate matrix in the demand model, a value of 100 percent should be input in this field.
    - Accident rate in vehicle per million vehicle-mile
    - Fuel consumption rates for trucks and automobiles
    - CO, HC, and NOx emission rates and the assumed vehicle class percentages in the emission calculations

- Analysis periods including the hours and days in each period and volume factors to convert the daily volume to volume in each period for use with daily demand models.

- Deployment parameters: These are parameters related to the implementation and operation of ITS deployment. They are deployment specific and will be described for each deployment in the chapters that discuss the individual deployments in the report.

- Analysis parameters: These parameters are required to analyze the performance of the system with and without ITS. Again, these parameters are deployment specific and will be described for each deployment in the chapters that discuss individual deployments.

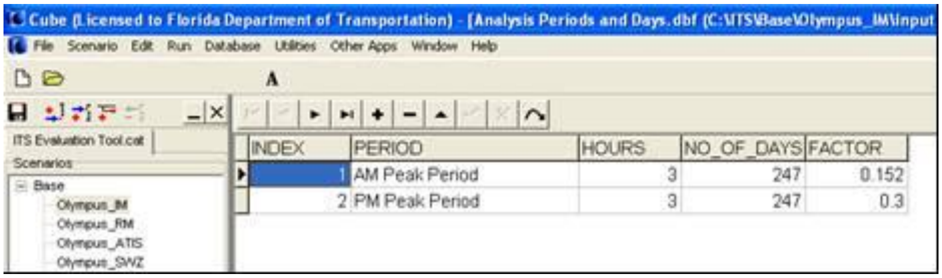
- Impact factors: These factors reflect the expected impacts of each ITS deployment on various performance measures in terms of percentage changes in the values of these measures. The impact factors will be described for each deployment in the chapters that discuss the individual deployments.

- Dollar values: These are the values used to convert the estimated benefits to monetary values including.
    - Dollar value of travel time
    - Dollar value of accidents
    - Dollar value of fuel consumption
    - Emission

- Equipment and cost parameters
    - Discount rate
    - Equipment and unit initial and recurrent costs

The analysis period input (which is listed as part of the demand parameters above) illustrated in

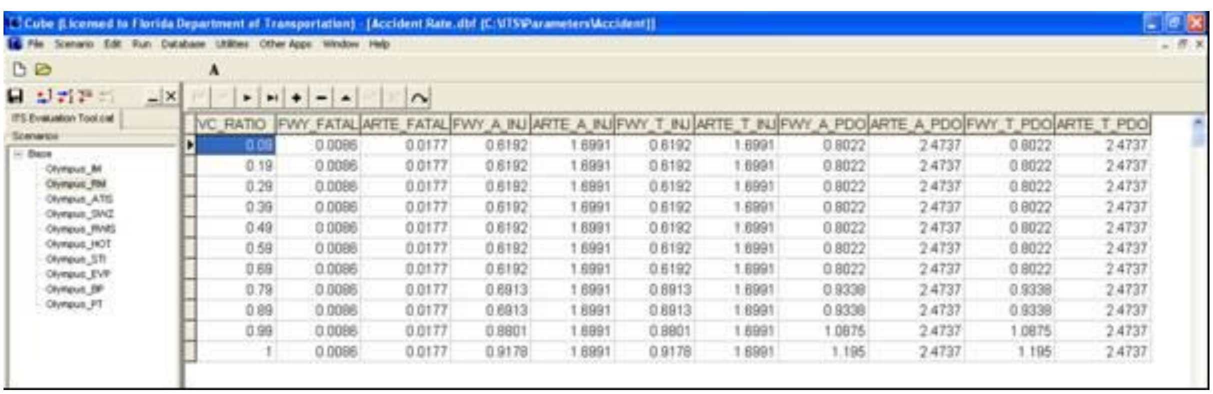
Figure 5-10. As shown in this figure, the user is required to specify an index for each period (a number), a name for each period (e.g., AM Peak), number of hours in each period, number of days per year to be included in the analysis for this period, and a volume factor to convert the daily volume estimated by the FSUTMS to volume during this period. If the loaded network is a time-of-day model rather than a daily model, then the input volume does not need conversion and a value of 1 should be used as the volume factor.



INDEX	PERIOD	HOURS	NO_OF_DAYS	FACTOR
1	AM Peak Period	3	247	0.152
2	PM Peak Period	3	247	0.3

Figure 5-10 Analysis Period Inputs

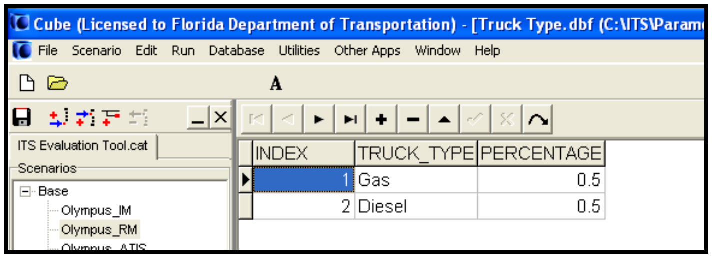
Figure 5-11 presents the input for accident rate, where the independent variable is the Volume/Capacity ratio ("VC_RATIO"), and the dependent variables are accident rate in terms of number of accidents per MVMT for fatalities along the freeways ("FWY_FATAL") and arterials ("ARTE_FATAL"), injury accident rate for autos along the freeways ("FWY_A_INJ") and arterials ("ARTE_A_INJ"), as well as for trucks on either the freeways ("FWY_T_INJ") or arterials ("ARTE_T_INJ"). Freeway and arterial property-damage-only accident rates for autos and trucks are specified in the "FWY_A_PDO", "ARTE_A_PDO", "FWY_T_PDO", and "ARTE_T_PDO" columns, respectively.



VC_RATIO	FWY_FATAL	ARTE_FATAL	FWY_A_INJ	ARTE_A_INJ	FWY_T_INJ	ARTE_T_INJ	FWY_A_PDO	ARTE_A_PDO	FWY_T_PDO	ARTE_T_PDO
0.09	0.0086	0.0177	0.6192	1.6991	0.6192	1.6991	0.8022	2.4737	0.8022	2.4737
0.19	0.0086	0.0177	0.6192	1.6991	0.6192	1.6991	0.8022	2.4737	0.8022	2.4737
0.29	0.0086	0.0177	0.6192	1.6991	0.6192	1.6991	0.8022	2.4737	0.8022	2.4737
0.39	0.0086	0.0177	0.6192	1.6991	0.6192	1.6991	0.8022	2.4737	0.8022	2.4737
0.49	0.0086	0.0177	0.6192	1.6991	0.6192	1.6991	0.8022	2.4737	0.8022	2.4737
0.59	0.0086	0.0177	0.6192	1.6991	0.6192	1.6991	0.8022	2.4737	0.8022	2.4737
0.69	0.0086	0.0177	0.6192	1.6991	0.6192	1.6991	0.8022	2.4737	0.8022	2.4737
0.79	0.0086	0.0177	0.6913	1.6991	0.6913	1.6991	0.9338	2.4737	0.9338	2.4737
0.89	0.0086	0.0177	0.6913	1.6991	0.6913	1.6991	0.9338	2.4737	0.9338	2.4737
0.99	0.0086	0.0177	0.8801	1.6991	0.8801	1.6991	1.0875	2.4737	1.0875	2.4737
1	0.0086	0.0177	0.9178	1.6991	0.9178	1.6991	1.195	2.4737	1.195	2.4737

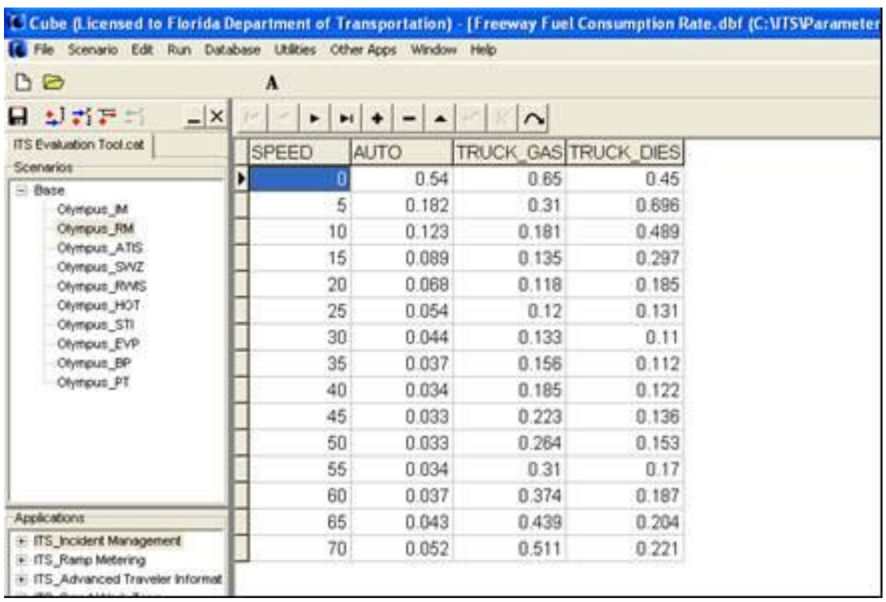
Figure 5-11 Accident Rate Inputs

Figure 5-14 presents the inputs associated with the fuel consumption module. The column “SPEED” in Figure 5-12 b and c is the vehicle speed, and the column “AUTO” corresponds to the fuel consumption rate for autos in units of gallons per VMT. The last two columns, “TRUCK_GAS” and “TRUCK_DIES,” include the fuel consumption rates for trucks that use gas and diesel, respectively.



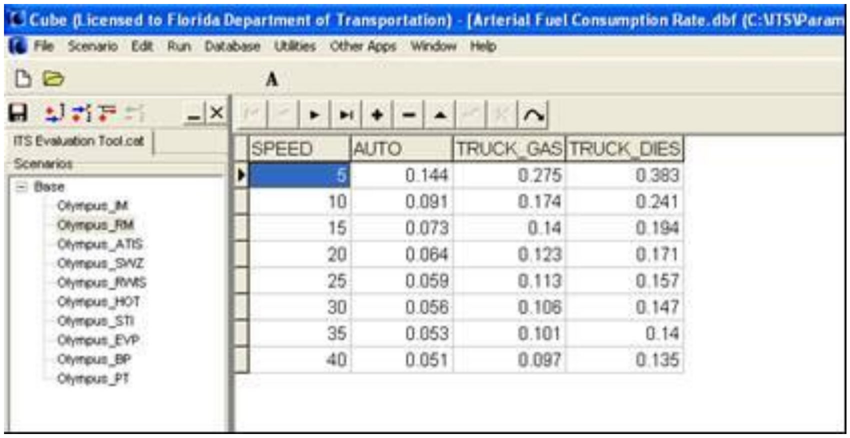
INDEX	TRUCK_TYPE	PERCENTAGE
1	Gas	0.5
2	Diesel	0.5

(a) Truck Type Percentage



SPEED	AUTO	TRUCK_GAS	TRUCK_DIES
0	0.54	0.65	0.45
5	0.182	0.31	0.696
10	0.123	0.181	0.489
15	0.089	0.135	0.297
20	0.068	0.118	0.185
25	0.054	0.12	0.131
30	0.044	0.133	0.11
35	0.037	0.156	0.112
40	0.034	0.185	0.122
45	0.033	0.223	0.136
50	0.033	0.264	0.153
55	0.034	0.31	0.17
60	0.037	0.374	0.187
65	0.043	0.439	0.204
70	0.052	0.511	0.221

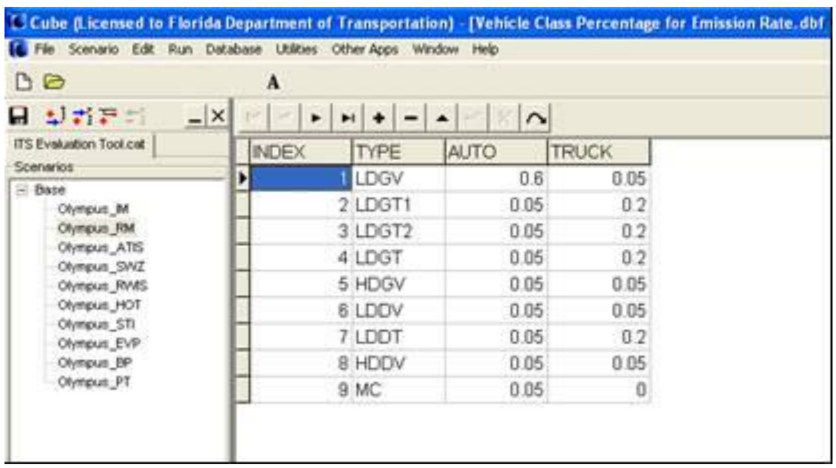
(b) Fuel Consumption Rates on Freeways



(c) Fuel Consumption Rates on Arterials

Figure 5-12 Inputs Associated with Fuel Consumption Module

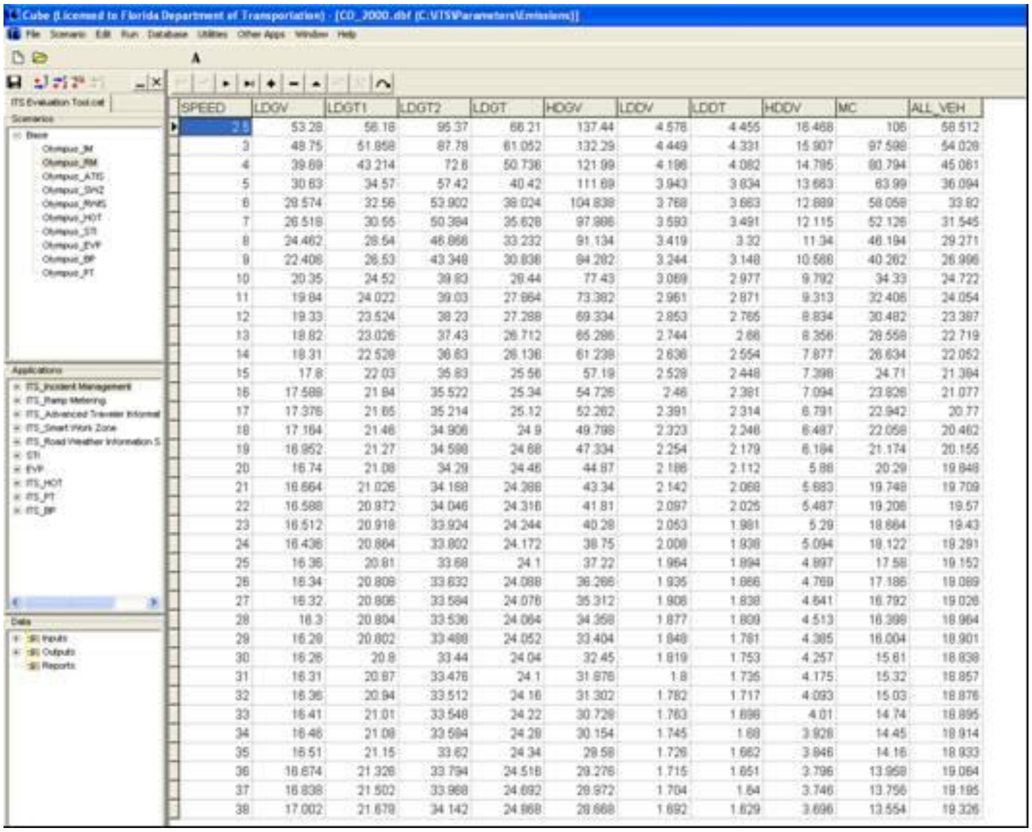
The emission module used in this study is based on Mobile6, as described earlier in document. Figure 5-13 presents the required inputs to this module. This module requires the knowledge of vehicle class percentages. The vehicle classes are included in the “TYPE” column. The corresponding percentages for autos and trucks are shown in the “AUTO” and “TRUCK” fields, respectively. The user can view and edit the emission rates for a specific year by clicking the arrows on the right hand side of the input box and selecting the corresponding files in the lists, as shown in Figure 5-14.



INDEX	TYPE	AUTO	TRUCK
1	LDGV	0.6	0.05
2	LDGT1	0.05	0.2
3	LDGT2	0.05	0.2
4	LDGT	0.05	0.2
5	HDGV	0.05	0.05
6	LDDV	0.05	0.05
7	LDDT	0.05	0.2
8	HDDV	0.05	0.05
9	MC	0.05	0

(a) Vehicle Class Percentages used in Emission Calculation

(b)



SPEED	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	ALL_VEH
2.5	53.28	58.18	95.37	66.21	137.44	4.576	4.455	16.468	106	58.512
3	48.75	51.858	87.78	61.052	132.29	4.449	4.331	15.907	97.598	54.028
4	39.69	43.214	72.6	50.736	121.99	4.196	4.082	14.785	80.794	45.061
5	30.63	34.57	57.42	40.42	111.69	3.943	3.834	13.663	63.99	36.094
6	28.574	32.56	53.902	38.024	104.838	3.768	3.663	12.889	58.058	33.82
7	26.518	30.55	50.384	35.628	97.986	3.593	3.491	12.115	52.126	31.545
8	24.462	28.54	46.866	33.232	91.134	3.419	3.32	11.34	46.194	29.271
9	22.406	26.53	43.348	30.836	84.282	3.244	3.148	10.566	40.262	26.996
10	20.35	24.52	39.83	28.44	77.43	3.069	2.977	9.792	34.33	24.722
11	19.84	24.022	39.03	27.864	73.382	2.961	2.871	9.313	32.406	24.054
12	19.33	23.524	38.23	27.288	69.334	2.853	2.765	8.834	30.482	23.387
13	18.82	23.026	37.43	26.712	65.286	2.744	2.66	8.356	28.558	22.719
14	18.31	22.528	36.63	26.136	61.238	2.636	2.554	7.877	26.634	22.052
15	17.8	22.03	35.83	25.56	57.19	2.528	2.448	7.398	24.71	21.384
16	17.588	21.84	35.522	25.34	54.726	2.46	2.381	7.094	23.826	21.077
17	17.376	21.65	35.214	25.12	52.262	2.391	2.314	6.791	22.942	20.77
18	17.164	21.46	34.906	24.9	49.798	2.323	2.246	6.487	22.058	20.462
19	16.952	21.27	34.598	24.68	47.334	2.254	2.179	6.184	21.174	20.155
20	16.74	21.08	34.29	24.46	44.87	2.186	2.112	5.88	20.29	19.848
21	16.664	21.026	34.168	24.388	43.34	2.142	2.068	5.683	19.748	19.709
22	16.588	20.972	34.046	24.316	41.81	2.097	2.025	5.487	19.206	19.57
23	16.512	20.918	33.924	24.244	40.28	2.053	1.981	5.29	18.664	19.43
24	16.436	20.864	33.802	24.172	38.75	2.008	1.938	5.094	18.122	19.291
25	16.36	20.81	33.68	24.1	37.22	1.964	1.894	4.897	17.58	19.152
26	16.34	20.808	33.632	24.088	36.266	1.935	1.866	4.769	17.186	19.089
27	16.32	20.806	33.584	24.076	35.312	1.906	1.838	4.641	16.792	19.026
28	16.3	20.804	33.536	24.064	34.358	1.877	1.809	4.513	16.398	18.964
29	16.28	20.802	33.488	24.052	33.404	1.848	1.781	4.385	16.004	18.901
30	16.26	20.8	33.44	24.04	32.45	1.819	1.753	4.257	15.61	18.838
31	16.31	20.87	33.476	24.1	31.876	1.8	1.736	4.175	15.32	18.857
32	16.36	20.94	33.512	24.16	31.302	1.782	1.717	4.093	15.03	18.876
33	16.41	21.01	33.548	24.22	30.728	1.763	1.698	4.01	14.74	18.895
34	16.46	21.08	33.584	24.28	30.154	1.745	1.68	3.928	14.45	18.914
35	16.51	21.15	33.62	24.34	29.58	1.726	1.662	3.846	14.16	18.933
36	16.674	21.326	33.794	24.516	29.276	1.715	1.651	3.796	13.958	19.064
37	16.838	21.502	33.968	24.692	28.972	1.704	1.64	3.746	13.756	19.195
38	17.002	21.678	34.142	24.868	28.668	1.692	1.629	3.696	13.554	19.326

(b) Example of Emission Rate Tables

Figure 5-13 Inputs Associated with Emission Module

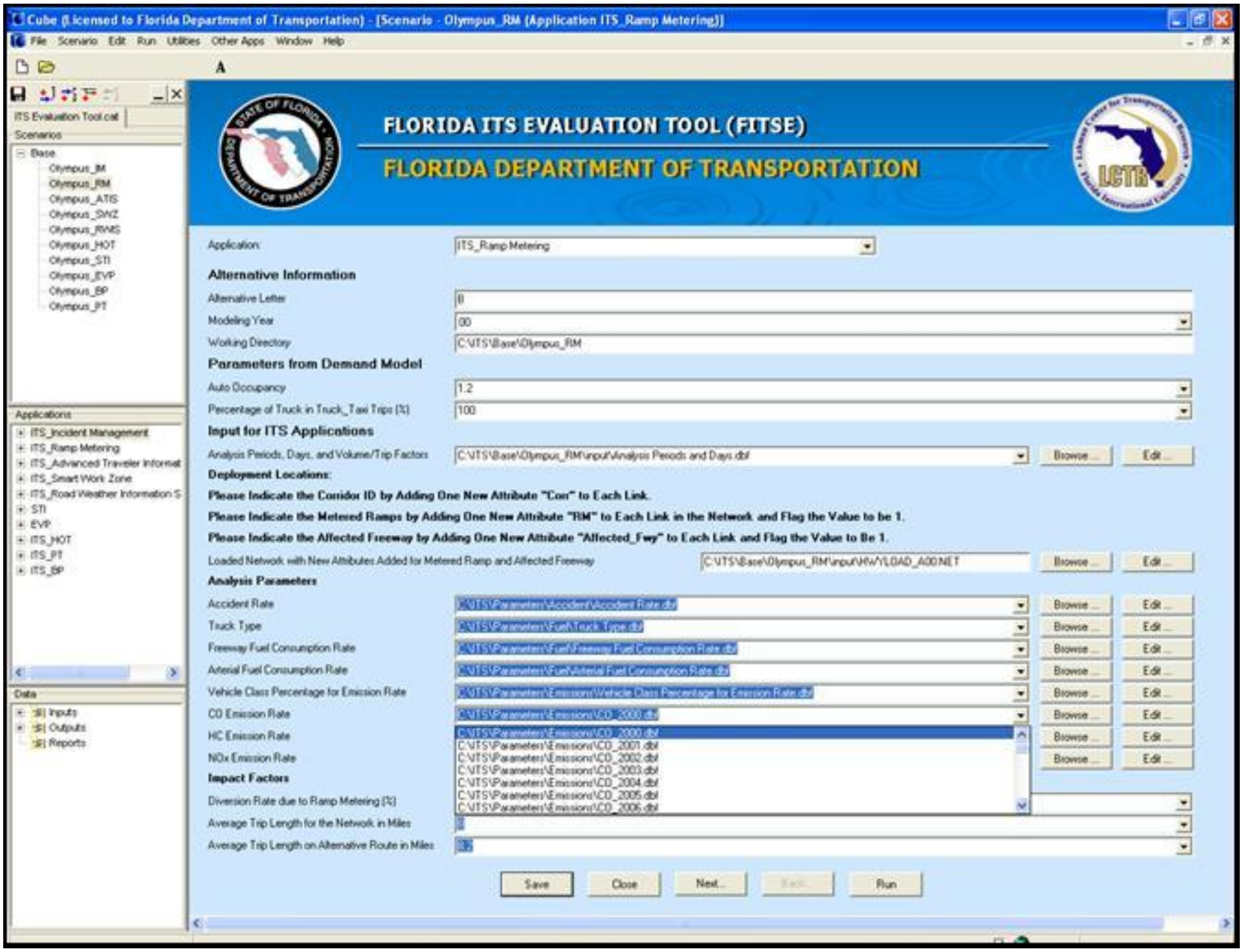
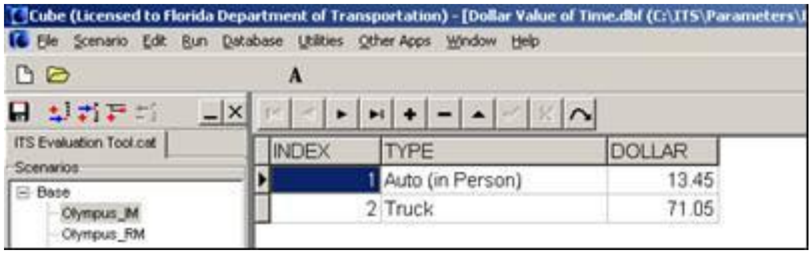
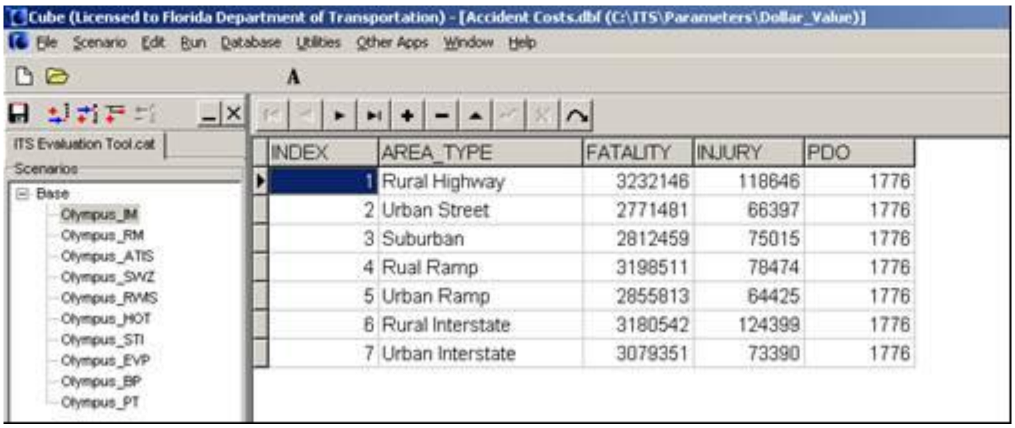


Figure 5-14 Selecting the emission module inputs for a Specific Year

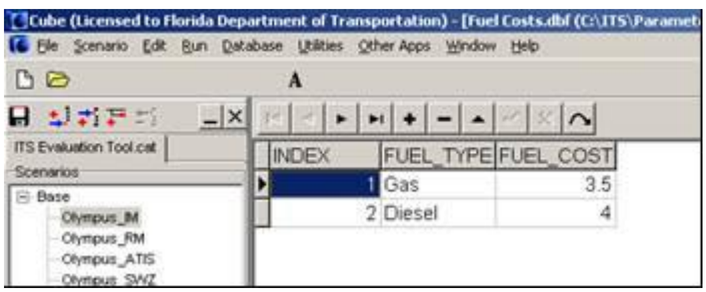
The dollar values used in this study are presented in Figure 5-15. The dollar value of time for auto is in the units of dollars per hour per person, which has to be converted into dollars per hour per vehicle by multiplying the average auto occupancy. The fuel costs are given per gallon. The dollar value for CO, HC, NOx emissions are provided per ton.



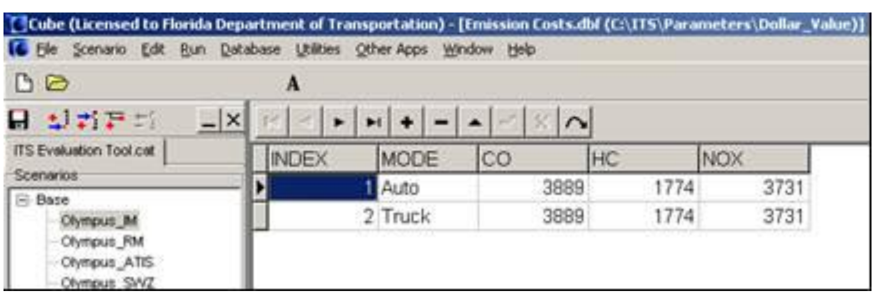
(a) Dollar Value of Time



(b) Accident Costs



(c) Fuel Costs



(d) Emission Costs

Figure 5-15 Inputs Associated with Dollar Value

5.2.5 Output Interface

The evaluation tool generates three standard output files: 1) performance summary, 2) benefits summary, and 3) benefits and costs summary. The three displays are organized under each ITS deployment output category in the data window. The output files are saved in the “output” folder in the Working Directory. Details of these files are presented in the following chapters that describe individual ITS deployments.

6 Incident Management and Driver Information Dissemination

Incident management is one of the most important components of Intelligent Transportation Systems (ITS). Its primary goals are: 1) coordinating the activities of transportation agencies, police, and emergency services; 2) facilitating incident detection, verification, response, and clearance; and therefore 3) reducing the incident duration and minimizing the negative impacts of incidents. The evaluation tool considers roadside driver dissemination subsystems as integrated parts of incident management. These subsystems include dynamic message signs and advisory highway radio. Thus, this chapter addresses both incident management as well as driver information dissemination.

6.1 Previous Approaches to Evaluation of Incident Management

This section presents a review of previous approaches to incident management systems and other studies that are related to evaluating incident impacts.

6.1.1 IDAS Methodology

Three types of incident management systems are considered in IDAS: 1) incident detection and verification systems, 2) incident response and management systems, and 3) a combination of these two types of systems. The evaluated benefits include the impacts on travel time delays, safety, and reductions in fuel consumption and emissions.

To estimate the reduction in incident delay, IDAS calculates the unadjusted incident delay rate D_u (vehicle-hours of delay per vehicle mile) for the baseline scenario (no ITS) as a function of the number of lanes, freeway traffic volume, level of congestion, and time period of analysis (indicating whether the analysis is done for the peak-hour, peak-period, off-peak, or daily). For the ITS scenario (with the incident management systems), the incident delay rate D_a is calculated based on the adjusted rate, as follows:

$$D_a = D_u(1 - R_f)(1 - R_d)^2 \tag{6-1}$$

where D_a is the adjusted delay rate (vehicle hours of delay per vehicle mile), and R_f and R_d are percentage reductions in incident frequency and incident duration, respectively. The D_u values are estimated based on the volume/capacity ratios (V/C) in no incident conditions, as produced by the model. The default value for incident duration reduction rate is 9 percent for incident detection and verification systems, 39 percent for incident response and management systems, and 51 percent for the combined incident management systems. The reduction in incident frequency in Equation 6-1 is assumed to be 0 percent. The incident delays with and without incident management deployments are calculated based on the adjusted and unadjusted incident delay rates, respectively.

Although not stated in the IDAS manual, this method is based on queuing theory equations with assumptions made regarding the incident frequency, frequency of lane blockage incidents, incident duration, and peaking characteristics of traffic within the analysis period. The assumed values of these variables are not listed in the IDAS manual and the users are not allowed to change these values.

IDAS estimates the safety benefits of incident management systems by assuming a reduction in fatalities due to accidents. It assumes that detection/verification systems and incident response/management systems individually reduce the freeway fatality rate by 10 percent, and reduce the fatality rate by 21 percent when combined. The model assumes that these reduced fatalities are shifted to injuries. IDAS estimates the baseline freeway fatality based on the V/C ratio, vehicle type, and facility type from look-up tables.

Base-line fuel consumption and emissions rates are first obtained based on estimated speeds, as described in Section 3. These rates are then reduced by 15 percent to account for the deployment of incident detection/verification systems, 27 percent for incident response/management systems, and 42 percent for the combined incident management systems in order to calculate fuel savings and emissions reductions. The user can change the default percentages.

IDAS includes tables that can be used to identify the D_u values (used in Equation 6-1) for analyses based on a three-hour peak period, a one-hour peak period, a 15-hour off-peak period, and daily traffic. Table 6-1 presents an example of these values for the three-hour analysis period.

Table 6-1 Travel Time Reliability Rate for Three-Hour Peak Period

Volume/One-Hour Capacity	Base Rate (Du) in veh-hr/veh-mile		
	2 Lane	3 Lane	≥ 4 Lane
0.15	3.71E-08	1.62E-09	5.45E-12
0.30	5.66E-07	5.21E-08	7.22E-10
0.45	2.79E-06	3.97E-07	1.26E-08
0.60	8.63E-06	1.68E-06	9.57E-08
0.75	2.07E-05	5.14E-06	4.61E-07
0.90	4.25E-05	1.28E-05	1.67E-06
1.05	7.78E-05	2.77E-05	4.95E-06
1.20	1.32E-04	5.41E-05	1.27E-05
1.35	2.09E-04	9.77E-05	2.91E-05
1.50	3.16E-04	1.66E-04	6.12E-05
1.65	4.60E-04	2.67E-04	1.20E-04
1.80	6.50E-04	4.13E-04	2.21E-04
1.95	9.01E-04	6.20E-04	3.89E-04
2.10	1.25E-03	9.12E-04	6.56E-04
2.25	1.77E-03	1.35E-03	1.07E-03
2.40	2.72E-03	2.12E-03	1.74E-03
2.55	4.77E-03	3.80E-03	3.01E-04
2.70	9.67E-03	8.28E-03	6.59E-03
2.85	1.49E-02	1.30E-02	1.02E-02
3.00	1.99E-02	1.74E-02	1.37E-02

6.1.2 ITSOAM

In ITSOAM, the change in queuing delay due to incident management is evaluated by using a queuing analysis approach and considering the reduction in incident detection and response time due to incidents. For the evaluation of safety benefit, a statistical expression is used to estimate the relationship between the reduction in the incident detection/response time and number of fatalities. Similar to the IDAS, ITSOAM also assumes that the reduced fatalities are converted to injuries. The emission and fuel consumption benefits are obtained by including the estimated changes in traffic speed, speed variation, and VMT in the calculation of emission and fuel consumption.

When evaluating service patrol benefits, the ITSOAM recommends the use of 35-60 percent reduction in response time, 15-25 percent reduction in clearance time, and 5 percent reduction in detection time.[28] ITSOAM assumes that when a CCTV system is

[28] Thill, J-C, and G. Rogova, "The ITS Options Analysis Model Technical Documentation," Produced for the New York DOT by Calspan UB Research Center and University at Buffalo, Buffalo, NY, October 13, 2005

deployed alone, it results in 0 percent reduction in detection time and 20 percent reduction in response time. CCTV deployed along with a detection system is assumed to result in 20 percent reduction in both the detection and response times. If an automated incident detection system is installed but a CCTV system is not, ITSOAM assumes 20 percent reduction in detection time and 0 percent reduction in response time.

6.1.3 FDOT District 4 Benefit-Cost Analysis

In the FDOT District 4 SMART SunGuide ITS operations benefit-cost analysis,[29] the incident delay reduction was estimated using a deterministic queuing analysis. The improvement in safety focused on the reduction in the fatalities due to faster response and reduction in secondary crashes. The benefits in fuel consumption and emissions in this report were determined based on the reduction in the vehicle-miles in the queue, which were also estimated using queuing theory. The route diversion resulting from DMS and traveler information systems were estimated based on the proportion of diverted motorists and the estimated differences between the route impacted by the incident and the alternative route.

6.1.4 North Carolina Service Patrol Assessment

This study developed a decision-support tool that allows the assessment of candidate freeway sections for service patrol operation. Two types of analyses were conducted: planning and operational. To perform the planning analysis, a performance index was calculated based on the values of the annual average daily traffic (AADT) per lane, crashes per mile per year, and crashes per 100 million vehicle miles. It was recommended that the freeway facilities should be ranked in terms of the need for service patrol based on this performance index.

The operational analysis entailed calculating the benefit/cost ratios based on traveler delay savings and the costs of service patrol. A macroscopic analysis model was used to examine the effects of service patrol on queuing and vehicle delays for different incident severities, facilities, and time periods. After running the analysis model for 440 combinations of these variables, the data were used to derive relationships between vehicle delays versus incident v/c ratios. These graphs were divided into separate models by the number of lanes, area type, and incident duration. Within each model, distinct equations were created for each incident severity. These estimated vehicle delay models served as the basis for determining the estimated delay savings from installing service patrol and as the basis for operational decisions.

[29] Hadi, M., L. Shen, C. Zhan, Y. Xiao, S. Corbin, and D. Chen, "Use of Operation Data to Evaluate the Benefits and Costs of Advanced Traffic Management Components," Transportation Research Record (in press), Washington, D.C., 2008.

6.1.5 California Berkeley Evaluation Tool

In order to calculate the benefits and costs of freeway service patrols (FSP), a method was developed[30] using Excel based on freeway geometry and traffic characteristics, and the frequencies and types of assisted incidents. The model calculates the total number of FSP-assists based on the proposed FSP service and the beat characteristics. It uses a statistical model derived from analysis of over 100 existing beats statewide to determine the number of occurring incidents.

This method calculates the delay per incident with and without service patrol using deterministic queuing analysis. It also calculates fuel consumption and emission savings. The response time reduction (RTR) due to FSP is calculated based on the difference between the time that the FSP tow-truck arrived at the incident and the time that a tow-truck would have arrived had there been no FSP service.

6.1.6 Cohen and Southworth's Incident Delay Study

Cohen and Southworth[31] developed equations to estimate the average incident delay rate as a function of volume/capacity ratio. These equations, presented below, were developed for freeways using queuing theory equations.

For roadways with two lanes in each direction:

$$ID = 0.01546\left(\frac{V}{C}\right)^{18.7} + 0.00446\left(\frac{V}{C}\right)^{3.93} \tag{6-2}$$

For roadways with three lanes in each direction:

$$ID = 0.01277\left(\frac{V}{C}\right)^{22.3} + 0.00474\left(\frac{V}{C}\right)^{5.01} \tag{6-3}$$

For roadways with two lanes in each direction:

$$ID = 0.007153\left(\frac{V}{C}\right)^{32.2} + 0.006533\left(\frac{V}{C}\right)^{7.05} \tag{6-4}$$

where *ID* represents the average incident delay rate due to all kinds of incidents in vehicle hours per vehicle mile, and *V/C* is the ratio of volume to capacity.

6.1.7 Additional Evaluation Results

[30] Davis, L., M. Mauch, and A. Skabardonis "Freeway Service Patrol Predictor Model: Methodology and Implementation", Presented at the 83rd Annual Meeting of the Transportation Research Board Washington, D.C. January 2004

[31] Cohen, H. and F. Southworth, "The Measurement and Valuation of Travel Time Variability Due to Incidents on Freeways," Journal of Transportation and Statistics, December 1999, pp. 123-131.

Below are some additional results obtained from previous evaluation studies of incident management systems:

- With the implementation of the Atlanta's NAVIGATOR system,[32] the time needed to dispatch a service patrol truck to the incident site was reduced from 21 to 10 minutes (52 percent) and the average clearance time dropped from 26 to 20 minutes (23 percent).
- On San Francisco's I-880 corridor, the implementation of a freeway service patrol reduced the average response time from 28.9 to 18.4 minutes (36 percent) and decreased clearance time from 9.6 to 8.1 minutes (16 percent).[33]
- A study in Colorado reported a reduction in response and clearance time of 10.5 minutes for lane blockage incidents and 8.6 minutes for non-lane blockage incidents due to the implementation of a service patrol program.[34]
- A study in Houston[35] reported that service patrol vehicles reduced total incident duration by 16.5 minutes.
- A study in the Puget Sound region, WA, found that the service patrol vehicles reduced incident response time for lane blocking incidents from 7.5 minutes to 3.5 minutes.[36]
- Based on a review of a number of studies, Khattak[37] found that service patrol vehicles reduces incident response time by 19 percent to 77 percent and incident clearance time by 8 minutes.
- In Minnesota, an evaluation of a service patrol program indicated a reduction in stall vehicle incident duration of eight minutes.[38]
- In Houston, incident response duration was reduced by 20 percent due to the implementation of the TransGuide traffic management system. The evaluated

[32] Presley, M.W. and K.G. Wyrosdick, "Calculating Benefits for Navigator, Georgia's Intelligent Transportation System," Georgia Department of Transportation, Atlanta, GA, 1998.

[33] Skabardonis, A., H. Noeimi, K. Petty, D. Rydzewski, P. Varaiya, and H. Al-Deek. "Freeway Service Patrol Evaluation. California PATH Program" Institute of Transportation Studies, University of California, Berkeley, CA, Working Paper UCB-ITS-PRR-95-5, 1995.

[34] Cuiciti, P., and. B. Janson, "Incident Management via Courtesy Patrol: Evaluation of Pilot Program in Colorad," Transportation Research Record No. 1494, Transportation Research Board, Washington, DC, 1995.

[35] Hawkins, P.A., "Evaluation of the Southwest Freeway Motorist Assistant Program in Houston," Report No. TX-94/1922-IF, Texas Transportation Institute, College Station, TX, 1993.

[36] Nee, J. and M. Hallenbeck, "Evaluation of the Service Patrol Program in the Puget Sound Region," Report T1803, Washington State Transportation Commission, 2001.

[37] Khattak, A., Roufhail N., Monast K., and Havel J., "A Method for Prioritizing and Expanding Freeway Service Patrols," Paper Presented at the Transportation Research Board 83rd Annual Meeting, Washington, D.C., January 2004.

[38] "Highway Helper Summary Report - Twin Cities Metro Area," Minnesota Department of Transportation, Report No. TMC 07450-0394. July 1994.

phase of the TransGuide system included dynamic message signs, lane control signs, loop detectors, video surveillance cameras, and a communication network covering 26 instrumented miles.[39]

- An evaluation of the CHART program conducted in the year 2000 estimated that the average incident duration was about 33 minutes with CHART and 77 minutes without it. In 1999, the average incident duration was estimated to be about 42 minutes with CHART and 93 minutes without it.[40]

6.1.8 Assessment

In the absence of field measurements that assess the reduction in delay due to incident management systems, one of three methods can be used to estimate the reduction in delay based on the reduction in incident duration: 1) queuing analysis, 2) shock wave analysis, and 3) simulation analysis. Traffic simulation analysis is a powerful method to analyze the benefits of traffic and incident management. However, the use of simulation models is expensive in terms of data collection requirements, model input preparation, and calibration.

When comparing queuing and shock wave analysis, queuing analysis is by far the most widely used method to identify incident impacts with and without incident management strategies. Detailed discussions of deterministic queuing analysis and shockwave analysis can be found in traffic flow theory textbooks.[41, 42] A study by Rakha and Zhang[43] has demonstrated the consistency in delay estimates that are derived from deterministic queuing theory and shock-wave analyses. The paper indicated that queuing theory provides a simple and accurate technique for estimating delay at highway bottlenecks. Thus, this study team decided to utilize the deterministic queuing analysis approach to calculate incident delay with and without incident management.

The ITSOAM tool evaluates the change in queue delay using a queuing analysis approach that considers the reduction in incident detection and response time. IDAS uses equations derived based on queuing analysis to estimate the delays due to incidents assuming incident frequencies and durations that users cannot change. Neither IDAS nor

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[39] Henk, R. H., Molina R.Z., and Inwin P. L., "Before-and-After Analysis of the San Antonio TransGuide System," Paper Presented at the 76th Annual Meeting of the Transportation Research Board, Washington DC. January 1997.

[40] Petrov, A., Lin P., Zou N., and Chang G., "Evaluation of the Benefits of a Real-Time Incident Response System," Paper presented at the 9th World Congress Conference on ITS, Chicago, Illinois. 14-17 October 2002.

[41] "Revised Monograph on Traffic Flow Theory." Federal Highway Administration, Washington D.C, 1997.

[42] May, A.D., "*Traffic Flow Fundamentals*." Prentice Hall Inc., Englewood Cliffs, New Jersey, 1990.

[43] Rakha, H. and Zhang, W. "Consistency of Shock-Wave and Queuing Theory Procedures for Analysis of Roadway Bottlenecks." Presented at 84th Annual Meeting of the Transportation Research Board, Washington, D.C., 2005.

ITSOAM consider the benefits of incident management on arterial streets due to the difficulty in estimating incident impacts on arterial streets.

6.2 Previous Approaches to the Evaluation of Driver Information Dissemination

6.2.1 IDAS Methodology

IDAS assumes that the deployment of freeway DMS affects the in-vehicle travel time. The travel time benefits are calculated by multiplying the following three items:

- The percentage that the message sign is turned on (default is 10 percent).
- The percentage of vehicles passing the message sign and save time (default is 28 percent).
- The default travel time saving per traveler (default is 11 minutes).

IDAS calculates the HAR benefits similarly by multiplying the following three variables:

- The percentage of traffic conditions that warrant HAR use (default is 10 percent).
- The percentage of vehicles that tune in to the broadcast (default is 5 percent).
- The percentage of tuned-in drivers that benefit from the HAR (default is 25 percent).
- The travel time saving per traveler (default is four minutes).

The monetary value of travel-time savings due to DMS and HAR is assumed to be three times the standard value since the savings in travel time due to incidents is assumed to be an improvement in travel time rather than travel time reliability. The IDAS manual states that the safety, emissions, and fuel benefits may not be statistically significant, since the diverted traffic may create additional travel on the arterials that offsets the benefits of the reduced congestion on the freeways.

6.2.2 ITSOAM

Four types of HAR and DMS applications (categorized by the types of information provided to motorists) are considered in the ITSOAM as follows:

- Limited descriptive information for the traffic congestion level (only indicating an incident ahead or congestion ahead),
- Descriptive information (not only showing the incident ahead but also indicating the number of lanes blocked or the possible delay/travel time),
- Detailed descriptive information (providing possible alternative routes), and
- Speed advisory messages.

With limited information, the diversion rate was assumed to be smaller. More enriched information is assumed to result in more diversion because a better understanding of the current congestion level allows the driver to make better route choices. ITSOAM uses a relationship developed by Huchingson and Dudek[44] that relates the expected delay and the diversion rate. Compared to having more limited information, this curve shifts to the left by ten minutes when the driver has the detailed descriptive information because it is likely that more people would divert.

The ITSOAM calculations of HAR and DMS travel-time benefits are represented by the change in overall delay before and after deployment. The travel time is assumed to include four components:

- Traversal time on the segment of the freeway,
- Merge delay from blocked lane to the free lane,
- Queue delay at the upstream of the incident location, and
- Delay related to the diversion from the freeway to the alternative route.

A Bureau of Public Roads (BPR) curve captures the traversal time on the freeway as a function of flow. The tool recognizes that vehicles exiting the freeway and bypassing the incident bottleneck are delayed beyond the normal non-incident time on the freeway section. The travel time on the alternate route is assumed to be a constant percentage above the incident-free traversal time on the main freeway section. Mannering's survey of Seattle commuters revealed that, on average, trip travel time on the shortest alternate route was about 25.7 percent longer than the most frequently used route during peak hours of the day. A study of urban route selection in Rome, Italy indicated that the alternative routes were 8 to 29 percent longer than the shortest route available.

ITSAOM assumes that the travel time on impacted roadway in normal conditions is 15 percent lower than the travel time on alternative routes. Depending on the flow relative to the capacity, merge delay, or queue delay may or may not exist. If the reduced capacity due to the accident is smaller than the flow, the merge delay is ignored and the queue delay is considered using a queue delay model. The merge delay is calculated based on the merging capacity of the neighboring lanes, which is a function of flow and acceptable gap for merge. The activations of the HAR and DMS increase the diversion flow rate, which in turn, reduces the overall delay. To calculate the benefit of DMS, the expected proportion of travelers who divert without traveler information has to be estimated. A field study on diversion behaviors indicated that this diversion is significant but small,[45] averaging 2 percent of freeway traffic, which is the value ITSAOM uses. The ITSOAM

[44] Huchingson, R.D., and C. Dudek, "Delay, Time Saved, and Travel Time Information for Freeway Traffic Management," Transportation Research Record, 722, 1979, 36-40.

[45] Dudek, C. L., W. Stockton, and D. Hatcher. "Real-Time Freeway-to-Freeway Diversion: The San Antonio Experience," Transportation Research Record, 841, 1982, 1-14.

uses a default value of 10 percent as the rate of vehicles diverting to an alternate route as a result of the basic information provided by the DMS. For detailed information provision, ITSOAM uses the modified Huchingson and Dudek relationship.

6.2.3 SCRITS

SCRITS users are required to provide the number of transmitters to be installed, the average volume through HAR unit reception area, the hours that transmitters are active for each incident, number of times per day each transmitter is activated, the percentage of drivers that tune to the broadcast, and the percentage of drivers hearing the radio that save time. The default values are 2,000 veh/hr passing the HAR reception area, two-hour activation of HAR for each incident, 0.2 times per day activation, 25 percent of drivers tune to the broadcast, and 25 percent of these drivers saving time. It is assumed that each vehicle can save 5 minutes by listening to the radio. The application of HAR is also assumed to reduce the secondary accidents by 0.7 percent. Any saving in emissions and vehicle operating costs are omitted.

The evaluation of Dynamic Message Signs in SCRITS is similar to that of HAR in that the user needs to input the number of times per day each sign provides incident information, hours of sign active for each incident, average volume drivers passing the message sign, percentage of drivers that save time (default value of 20 percent), and the amount of time saved (default value of 3 minutes). To evaluate the safety benefits, SCRITS assumes a 4.2 percent reduction in secondary accidents. Changes in emissions and vehicle operating costs are ignored.

6.2.4 Additional Evaluation Results

This section presents a review of studies conducted to research diversion behaviors of drivers in response to provided travel information. This review is necessary for the purpose of this study to help in selecting a methodology and associated parameters to estimate the benefits of the provided information to travelers.

Several researchers have used the stated preference approach in an attempt to determine the expected percentages of diverted travelers. Based on these type of surveys, the studies concluded that dynamic message signs (DMS) advising of the congestion ahead with no additional information concerning expected delay time or possible alternate routes can result in up to 60 percent of the freeway traffic to exit the freeway ahead of the bottleneck.[46,47,48,49,50] However, actual observation of diverted traffic found significantly

[46] Madanat, S., C.Y. Yang, and Y.M. Yen. "Analysis of Stated Route Diversion Intentions Under Advanced Traveler Information Systems Using Latent Variable Modeling," Transportation Research Record, 1485, 1995, 10-17.

[47] Benson, B.G., "Motorist Attitudes About Content of Variable-Message Signs," Transportation Research Record, 1550, 1996, 48-57.

lower diversion rates. For example, in Long Island, NY, an evaluation of the INFORM ATMS project indicated much lower traffic diversion rates,[51] with 5 to 12 percent of mainline traffic diverting to alternate routes in typical incident conditions. On the other hand, Tarry and Graham reported that several European field studies have found that the diversion rates range between 27 and 44 percent.[52]

A study[53] conducted on a freeway corridor in Honolulu, Hawaii, simulated incident duration and motorist response to real-time traffic information. The study assumed that 15 percent of motorists would reroute to avoid major incidents if no traffic management program was in place and 40 percent would reroute if an incident management programs were in place.

Srinivasan and Krishnamurthy[54] compared the impacts of DMS messages using the DYNASMART mesoscopic simulation/dynamic traffic assignment when assuming compliance rates to be 100 percent (to reflect idealized conditions) and with 40 percent compliance. The 40 percent rate was chosen based on the European field studies reported by Tarry and Graham as mentioned above.

Mahmassani[55] assumed that travelers switch routes under information based on boundedly rational switching behavior. According to this assumed behavior, as long as the difference between travel time on the subject route and alternative routes is below a certain threshold, the travelers will not change the route choice. In this route choice framework, a user will switch from the current path (the freeway corridor where the incident occurs) to an alternative route, only if the travel-time savings are at least a certain percentage less than the travel time on the current path and at least a certain absolute time. Both of these thresholds are assumed to vary randomly across users, with a

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[48] Barfield, W., L. Conquest, J. Spyridakis, and M. Haselkorn. “Information Requirements for Real-Time Motorist Information Systems,” In Proceedings of the Vehicle Navigation and Information Systems Conference (VNIS), New York, IEEE, 1989, pp. 101-112.

[49] Bonsall, P., P. Firmin,, M. Anderson, I. Palmer, and P. Balmforth,, “Validating the Results of a Route Choice Simulator,” Transportation Research C, Vol. 5, No. 6, 1997, pp 371-387.

[50] Chatterjee, K., N.B. Hounsell,, P.E. Firmin, and P. W. Bonsall, “Driver Response to Variable Message Sign Information in London, Transportation Research Part C, 10(2), 149-169, 2002

[51] Smith, S.A. and C. Perez. “Evaluation of INFORM: Lessons Learned and Application to Other Systems,” Transportation Research Record, 1360, 62-65, 1992.

[52] Tarry, S. and A. Graham, “The Role of Evaluation in ATT Development,” Traffic Engineering and Control 36 (12), 1995, PP. 688- 693

[53] Prevedouros, P. and K. Kasamoto, “Incident Management Simulation on a Two Freeway Corridor in Honolulu,” A Paper presented at the 6th World Congress Conference on ITS, Toronto, Canada. 1999

[54] Srinivasan, K. and A. Krishnamurthy, “Role of Spatial And Temporal Factors in VMS Effectiveness Under Non-Recurrent Congestion,” Paper Presented at the 2003 Annual Meetings of the Transportation Research Board, Washington, DC, 2003.

[55] Mahmassani, H.S., “Dynamic Models of Commuter Behavior: Experimental Investigation and Application to the Analysis of Planned Traffic Disruptions,” Transportation Research A, Vol. 24, No. 6, 465-484.

mean of 1 minute and 20 percent respectively, determined empirically from user behavior studies under travel information.[56]

Kang et al.[57] divided the demand data during the peak period into 10 categories, and the diversion rate was classified into 5 cases from 3 percent to 15 percent. The corresponding benefits were calculated by applying IDAS.

Abi et al.[58] studied Route Comparison Information (RCI) boards that were installed on the Hanshin Expressway in Japan to provide travel time information on competitive routes so that the road users can select the optimum route to their destination. The study revealed that the installation of a RCI board at Maya on Route 3 Inbound might increase the average diversion rate for recurring congestion by 3.7 percent, resulting in an average time savings of 9.8 minutes per vehicle. The RCI board for non-recurrent congestion reduced the travel time by 38 minutes per vehicle during an accident.

Peeta et al.[59] investigated the impacts of DMS information content and other relevant factors on diversion rate. The Stated Preference (SP) method was applied in the analysis by means of an on-site survey. The survey results at the Borman Expressway in Indiana indicated that 53 percent of the drivers would divert to an alternative route when the expected delay on the current route is greater than 10 minutes. More than 70 percent of the survey participants would divert under adverse weather, while about 65 percent of respondents would choose alternative route during nighttime. The study survey indicated that the diversion rate when the DMS only indicated the occurrence of an accident is almost the same as the diversion rate when only the location of the accident is indicated by DMS, but the diversion rate increases as the expected delay or alternative route information is displayed on the DMS. Based on the survey data, a binary logit model was developed to predict the probability of diversion under DMS for truck drivers, non-truck drivers, and mixed drivers. The results showed that there is a large difference between the stated diversion behavior of truck drivers and that of non-truck drivers.

Based on a stated preference survey, Khattak et al.[60] investigated the effects of real-time traffic information on diversion behaviors. The study found that 42.9 percent of respondents would definitely take alternative routes under jammed condition.

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[56] Liu, Y. H., and H.S. Mahmassani, "Dynamic Aspects of Commuter Decisions under Advance Traveler Information Systems – modeling framework and experimental results," Transportation Research Record, Vol. 1645, 111-119.

[57] Kang W., J. Kim, K. Choi, S. Lee and Y. Choi, "Benefit Quantification of Collective Traveler Information System: Focusing on VMS Investment over National Highway Network," 12th World Congress on ITS, San Francisco, November, 2005.

[58] Abe A., M. Shimizu and T. Daito, "Evaluation of Route Comparison Information Boards on Hanshin Expressway," AP3169, The 5th World Congress Conference on ITS Orlando, Florida.

[59] Peeta, S., J.L. Ramos, and R. Pasupathy, "Content of Variable Message Signs and On-line Driver Behavior," Transportation Research Board 79th Annual Meeting, Washington DC, January, 2000.

[60] Khattak, A. J., F.C. Koppelman and J.L Schofer, "Stated Preferences for Investigating Commuters' Diversion Propensity." Transportation, Vol. 20, 1993, pp. 107-127

As stated in the previous section, the ITSOAM uses the relationship between the expected delay and the diversion rate developed by Huchingson and Dudek[61] to determine the diversion rate. This relationship assumes that the diversion occurs once the posted delay is greater than zero. As the posted delay approaches one hour, the diversion rate is close to 95 percent. Between these two limits, the diversion rate is assumed to gradually increase with the increase in the posted delay. This relationship is modified for use when evaluating more detailed descriptive information to account for the higher likelihood of people diverting with this type of information. However, the maximum diversion rate is close to 100 percent, which may not be reasonable, since research results show that only a fraction of the travelers are willing to divert, as stated above. In addition, as more travelers divert to alternative routes, the alternative route becomes more congested, which greatly reduces the benefits of diversion.

6.2.5 Assessment

As stated above, IDAS assumes that the benefits per diverted vehicle is assumed to be constant and is not affected by traffic or incident conditions. In addition, driver information dissemination is treated as a separate component from incident management with the number of DMS activations are set as a user input independent of the number of the incidents on the freeway. In reality, the number of DMS activations is a function of the total number of incidents and/or the number of lane blockage incidents, depending on the policy of DMS activation in the region. In addition, as discussed in the review presented in the above section, the diversion rate and savings due to this diversion is expected to be a function of the incident severity and the conditions in the network.

6.3 Requirement Analysis

This section presents requirements for the evaluation of incident management system as part of the developed Tool.

- The user shall be able to specify the freeway links with incident management components.
    - The user shall be able to specify all links in a facility type to have incident management.
- The Tool shall be able to calculate the improvement in incident benefits for each period specified in the analysis.

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[61] Huchingson, R. D. and C.L. Dudek, “Delay, Time Saved, and Travel Time Information for Freeway Traffic Management,” Journal of the Transportation Research Record, No. 722, TRB, National Research Council, Washington, D.C., 1979, pp. 36-40.

- The Tool shall be able to estimate the benefits of incident management in terms of improvements in incident delays, safety, fuel consumption, environmental impacts, and user monetary benefits.
- The calculation of benefits shall take into consideration the demand, prevailing capacity, frequency of different types of incidents, reduction in capacity due to different types of incidents, and reduction in incident duration.
- The Tool shall have default values for the rates of different types of incidents, reduction in incident duration, and reduction in capacities due to different types of incidents.
- The cost calculations of incident management shall include the initial and recurrent costs of CCTV cameras, traffic detectors, service patrol, and traffic management center operations.
- The user shall be able to select the (links) on which a DMS or HAR will be implemented.
- The Tool shall calculate the number of DMS or HAR activation based on the estimated lane blockage incidents on the links for which the DMS or HAR will provide incident information
- The Tool shall calculate the number of travelers diverting in response to DMS or HAR messages based on the incident conditions.
    - The diversion rate should be based on the details of the information provided to the user.
    - The Tool shall not assume diversion to alternative routes if the diversion is determined to produce negative benefits in terms of travel time delay
- The Tool shall calculate the reduction in delay on the links with incidents due to diversion based on incident severity and traffic conditions on the link
- The Tool shall account for the increase in travel time due to diversion to alternative routes

6.4 Incident Management Evaluation Methodology

This section discusses the methodology used in this study to evaluate incident management systems. The deployment of incident management reduces the incident duration and thus the incident delays. Deterministic queuing analysis is utilized to calculate incident delays with and without incident management. Based on the queuing analysis, the total delay for all the vehicles due to one occurrence of each class of incident (classified by the number of block and open lanes) is estimated. These estimates are then multiplied by the number of incidents (by incident class) per year to yield the total annual incident delay. Default values for incident frequency, duration, and lane blockage statistics are identified based on data obtained from a detailed incident management database maintained by the FDOT District 4 ITS program.

Improvement in safety is another important benefit from the application of incident management systems. As in IDAS, it is assumed that 21 percent of fatalities are shifted to injuries due to quick incident detection, verification, and response of incident management systems. However, in addition to the above benefits, a reduction in accident rate is assumed due to an expected reduction in secondary accidents since the incident management system reduces the period of time that the hazardous driving conditions exist due to primary incidents. In San Antonio, Texas, the crash rate decreased by 2.8 percent due to the implementation of incident management.[62] Thus, an additional reduction factor of 2.8 percent is used in this study for fatal, injury, and PDO accidents due to incident management.

Instead of using default reduction factors for emissions and fuel consumption due to incident management as is done in IDAS, the FSUTMS implementation calculates the emission and fuel consumption with and without incident management based on the speeds of queued and non-queued vehicles and the vehicle-miles in queue. Outside the queue, the speed is calculated using the relationship between speed and volume/capacity ratios, calibrated for the traffic demand forecasting models of the region. With incidents, the average queue length is obtained by using the queuing equations. The speed within the queue is assumed to be 2.5 mph. The average queue length as produced by the queuing equations is in the unit of vehicles. This number is converted from vehicles to feet based on assumed vehicle distance headway in the queue.

In addition to the benefits discussed above, as a part of incident management program, road rangers provide free-of-charge services, such as the tire changes, jump-starts, assisting the minor incidents, etc., to motorists needing assistance as well as to the Florida Highway Patrol (FHP). The additional benefits resulting from the road ranger service patrol may be evaluated by considering the number of activities performed by the road rangers and corresponding activity costs that road rangers save.

6.5 Information Dissemination Evaluation Methodology

This section describes the methodology used to evaluate information dissemination using DMS and HAR. The default value for the number of DMS or HAR activations per year is assumed to equal to the number of lane blockage incidents per year. The user can change this default value. The rationale behind the use of this default value is that many agencies (including those in Florida) generally display incident information on the DMS only when lane-blocking incidents have occurred.

This study assumes that the net diversion rate (defined as the difference between diversion when information is provided and when information is not provided) is a function of the potential savings in delay due to the incidents, as shown in Figure 6-1. If the calculated savings in delay is less than a certain minimum delay threshold (5 minutes

[62] "Intelligent Transportation Systems 2005 Update Benefits, Costs, and Lessons Learned." Prepared for Federal Highway Administration, US Department of Transportation, May 2005.

is used as the default value in this study), the diversion rate is assumed to be zero. This is based on the findings reported by Peeta, et al.[63] and Mahmassani[64] as discussed above. When the calculated savings in delay is high enough, the rate of diversion is assumed to be a maximum default value selected to be 40 percent, based on what is reported by Khattak et al.[65] and Peeta et al.[63] The user can change the minimum and maximum diversion rate threshold. Between the minimum delay and the maximum diversion rate thresholds, a linear relationship is assumed, as indicated in Figure 6-1.

The total time savings resulting from dynamic message signs are assumed to be the difference between the incident delay without DMS and the delay with DMS. These delays are calculated using the queuing equations (with reduced volumes due to additional diversion). However, to account for the extra time spent on the alternative diversion route compared to the original route, an increase in travel time is assumed for the diverted travelers that depend on the average length and the percentage of diversion to freeways versus arterials on the alternative route as input by the user. The program internally calculates the average V/C ratios on these alternative routes for use in the model.

The evaluations of the DMS and HAR will be similar. It is recommended however, to use the lower number associated with diverting traffic in HAR.

[63] Peeta, S., J.L Ramos and R. Pasupathy, "Content of Variable Message Signs and On-line Driver Behavior." In Transportation Research Record: Journal of the Transportation Research Record, No. 1725, TRB, National Research Council, Washington, D.C., 2000, pp. 102-108.

[64]Mahmassani, H. S., "Dynamic Models of Commuter Behavior: Experimental Investigation and Application to the Analysis of Planned Traffic Disruptions," Transportation Research A., Vol. 24, No. 6, 1990, pp. 465-484.

[65] Khattak, A. J., F.C. Koppelman and J.L Schofer, "Stated Preferences for Investigating Commuters' Diversion Propensity," Transportation, Vol. 20, 1993, pp. 107-127.

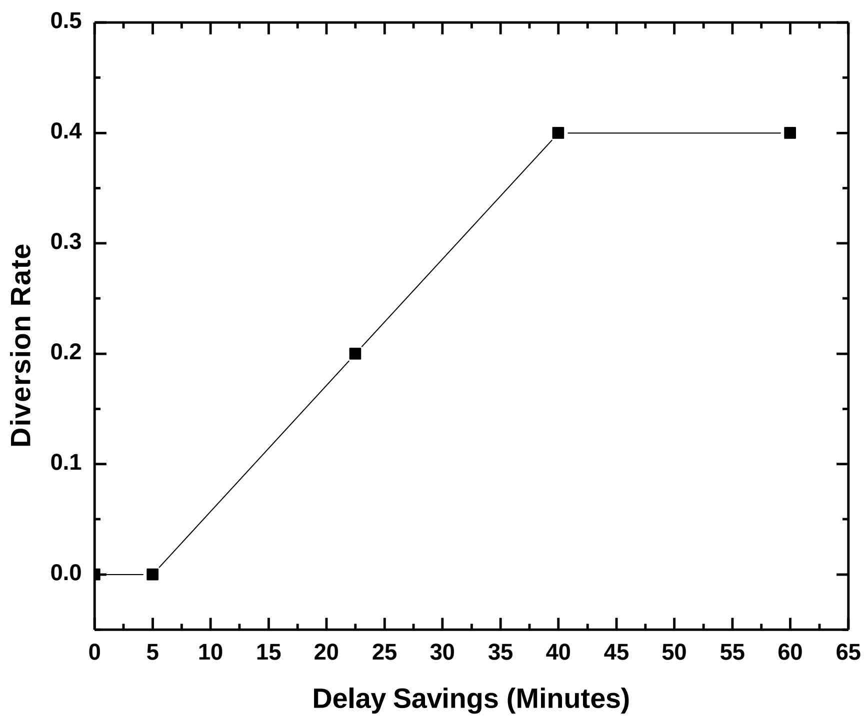

Figure 6-1 Relationship between diversion rate and delay savings used in this study

6.6 Costs

The cost of incident management includes the costs associated with a number of components, as discussed below.

6.6.1 Traffic Management Center Cost

Traffic management center costs are major components of ITS investment in urban areas. They can be used for the central operation of incident management, advanced traveler information, ramp metering, smart work zone management, and road weather information systems. Thus, these components share their costs.

Based on costs obtained from FDOT Districts 2, 4, 6, and 7 in a previous FDOT project[66] (this project is referred to as the "Florida-specific parameters project" throughout the remainder of this document) and further study of FDOT District 4 operations, we conclude that the basic facility, software, and hardware costs for freeway management centers range from $4,000,000 to $8,000,000. The annual operation and maintenance cost is estimated to range from $250,000 to $750,000, and the labor cost is estimated to range from $800,000 to $1,700,000. The default costs that can be used in the analysis are:

[66] Hadi, M.A., D. Quigley, P. Sinha, and A. Krishnamurthy, "Intelligent Transportation Systems Deployment Analysis System Customization," Final Report Prepared for the FDOT by PBSJ, Inc., Tallahassee, FL, October 27, 2005.

- 5,000,00 and 8,000,000 as the basic facility, software and hardware capital costs for small and large cities, respectively.

- 800,000 and 1,700,000 as the operation and maintenance costs for small and large cities, respectively.

One of the challenges is to distribute the traffic management costs (those for software, hardware, personnel and coordination, etc.) among ITS deployments. Two approaches can be considered to allocate the overhead cost. The first is the Relative-Budget-Activity (RBA) cost allocation, which allocates the overhead cost according to the ratio of the component's budgeted activity in proportion to the total budgeted activities.[67] The second is the Activity Based Cost Management (ABCM) method based on the processes performed within the organization that add cost and value to the products and services produced.[68] Because of the difficulty in collecting data for the ABCM approach, it was decided to use the RBA method for allocating the overhead cost to different components.

6.6.2 Communication Costs

As with TMC costs, communication costs can be distributed among a number of ITS components using the RBA method. Based on costs obtained during the Florida-specific defaults mentioned above and further study of FDOT District 4 operations, the following can be concluded regarding the communication costs:

- Fiber optic cable with junction boxes, splicing, termination, and conduit together with the required receivers/transceivers (or switches) were estimated to cost from \$85,000 to \$120,000 per mile.
- Costs for leased telephone lines with 56 KB/sec transmission capabilities were estimated to be \$2000 per year, as provided by District 2. The low and high annual costs for T1 and T3 leased telephone lines were estimated to range from \$5,600 to \$10,000, and \$25,000 to \$132,000, respectively.
- Fiber optic cable in existing conduit was estimated to cost between \$20,000 and \$30,000 per mile [1.6 kilometers] for the backbone, and \$15,000 per mile [1.6 kilometers] for lines branching from the backbone.
- Wireless data receivers and transceivers were estimated to be \$15,000 for connection at two points at 1 mbps, using 900 MHz, 802.11a, or 802.11b technologies.

If no additional information is available, the default communication media that is recommended for the analysis is fiber-optic communication. The length of the fiber optic cable can be calculated to equal the sum of the lengths of the links with ATMS devices as

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[67] Wei, D., "Inter-Departmental Cost Allocation and Investment Incentives," Review of Accounting Studies, March 2004.

[68] Dale, D. Activity Based Cost Management. Australian Accountant, Volume 61, No.3, Melbourne, Australia, March 1991, pp 64-69..

the user specifies. The default cost of the fiber can be assumed to be $105,000 per mile. The user will have the opportunity to specify an additional fiber optic infrastructure length for connecting from the managed corridor to the TMC plus an additional length.

The user will also be able to specify that for certain links wireless or leased telephone services will be provided. In these cases, the user must supply the communication costs for these links since these are only used in special cases and their cost varies widely by application. The RBA method will be used for allocating the communication cost to different components that utilize the communication system, as discussed above.

6.6.3 Other Incident Management Component Cost

Additional incident management cost includes the cost of CCTV cameras, traffic detectors, service patrols, and the SIRV. Below is a discussion of these costs.

Cameras

For freeways, the cost of a furnished and installed CCTV camera ranges between $16,000 and $18,000 (based on data obtained from FDOT District 6, FDOT District 7, and OOCEA obtained in the Florida-specific parameters project along with the cost estimates performed in the present study). The above numbers include the CCTV camera assembly and the associated hardware. The Florida-specific parameter project report indicated that the cost of the pole ranges from $5,000 for a 50 ft concrete strain pole to $32,500 for a 90-foot steel Abacus pole. Since the use of a 90-foot [27.4-meter] pole is required only for special conditions, it is reasonable to assume a range of $5,000 to $12,000 for freeway camera poles.

Information obtained recently from FDOT District 2 indicates that the cost of a CCTV camera assembly and poles is about $28,000 (including design, mobilization, MOT, and CEI). Thus, a default value of $18,000 will be used for CCTV camera assembly and $10,000 for the CCTV pole. In most applications, one CCTV camera per mile is used; this is the value that is recommended for use in this study.

According to the FDOT Florida-specific parameters project report, the reported O&M costs for cameras range between $1,200 and $4,000 per year, with three of the four responding agencies to that project survey estimating an annual O&M cost to be close to $4,000. Recent numbers obtained from FDOT District 4 indicates that the O&M cost is about $3,500 per camera. This value will be used as the default value.

The agencies estimated a five to eight-year CCTV camera lifetime, indicating that a five to six year life cycle is a reasonable assumption. The lifetime of the pole can be assumed to be 20 years.

Traffic Detectors

Most of existing traffic management systems in Florida use true-presence microwave traffic detectors. Based on information from FDOT District 6, Broward and Lee counties, and other sources, the Florida-specific parameters project concluded that a default loop detector capital cost of about $5,000 per detection station location per two-lane of the freeway and between $7,000 and $12,000 per intersection is reasonable. Two detection stations per mile can be assumed as the default since most agencies use half-mile spacing between stations. The VID cost was estimated to range from $34,000 to $38,000 per direction for freeways, including the camera pole, and $16,000 to $20,000 per intersection for arterials. The true presence microwave cost was estimated to range from $5,000 to $11,500, depending on whether the devices are mounted on new or existing poles. Data obtained recently from FDOT District 2 indicated that the cost of true presence detector per location is $10,500 including design, mobilization, MOT, and CEI. The default values used in this study analysis will be $11,000 per detector. Four true presence microwave detection stations will be assumed per mile (two in each direction of travel). It will be assumed that the operation and maintenance cost per microwave detector is $400 per year and that of loop detectors is $600 per two lane per location based on the results of the Florida-specific parameters project.

Service Patrol Cost

This cost varies by the number of service patrol vehicles per beat, the area of coverage for each beat, and the number of vehicles in different shifts. These variables vary per location in an urban area. Based on data obtained from FDOT District 4, the service patrol program in Broward County costs about $2,500,000 per year and cover 57.8 center-miles of freeway corridors. Thus, this study will use a default value for the cost of the service patrol program of about $43,250 per mile per year for 24 hours per day and 7 days per week operation.

6.6.4 Driver Information Dissemination Cost

Based on the results of the Florida Florida-specific parameters project mentioned earlier, it appears that good values for DMS capital cost range between $90,000 and $120,000 (the default of $105,000 can be used). Good values for DMS structure cost range between $90,000 and $120,000 for freeways (with a default of $105,000). Higher costs may be anticipated for special cases such as I-95 in Miami, where structure costs as high as $200,000 to $250,000 were reported. The annual O&M cost for freeway DMS, estimated by the respondents, appears to be between $15,000 and $25,000 based on FDOT Districts 4 and 7 data. The default O&M cost can be assumed to be $23,000 per sign. The DMS life cycle was estimated to be 10 years for the DMS and 20 years for the structures in the Florida-specific parameter project.

The HAR cost is estimated based on the results of the Florida Customized Benefit and Cost project to range between $58,000 and $62,000 (with an average of $60,000). The maintenance cost is estimated to be $2,000 to $3,000 per year at an average of $2,500.

Based on data obtained from District 4, one dynamic message sign is assumed in this study to be installed per 1.5 to 2.5 mile of freeway in both directions (three to five miles in one direction). HAR covers a five-mile area. Thus, it will be assumed that a HAR will be needed for every five miles, when deployed. The above parameters, as with other default parameters identified in this study, should be substituted by values that reflect the local conditions when such information is available

6.7 Implementation

The evaluation methodology presented in the previous section is implemented in the FSUTMS/Olympus model, using the script language of the Cube software, which is the modeling engine of the FSUTMS as described in Chapter 5.

6.7.1 Modeling Structure

The evaluation of incident management was implemented utilizing the modeling structure described in Section 5.3. Figure 6-2 presents the details of the structure of the submodule that calculates the time savings due to incident management. As described in the methodology section of this chapter, this is one of the most important submodules when calculating the benefits of incident management.

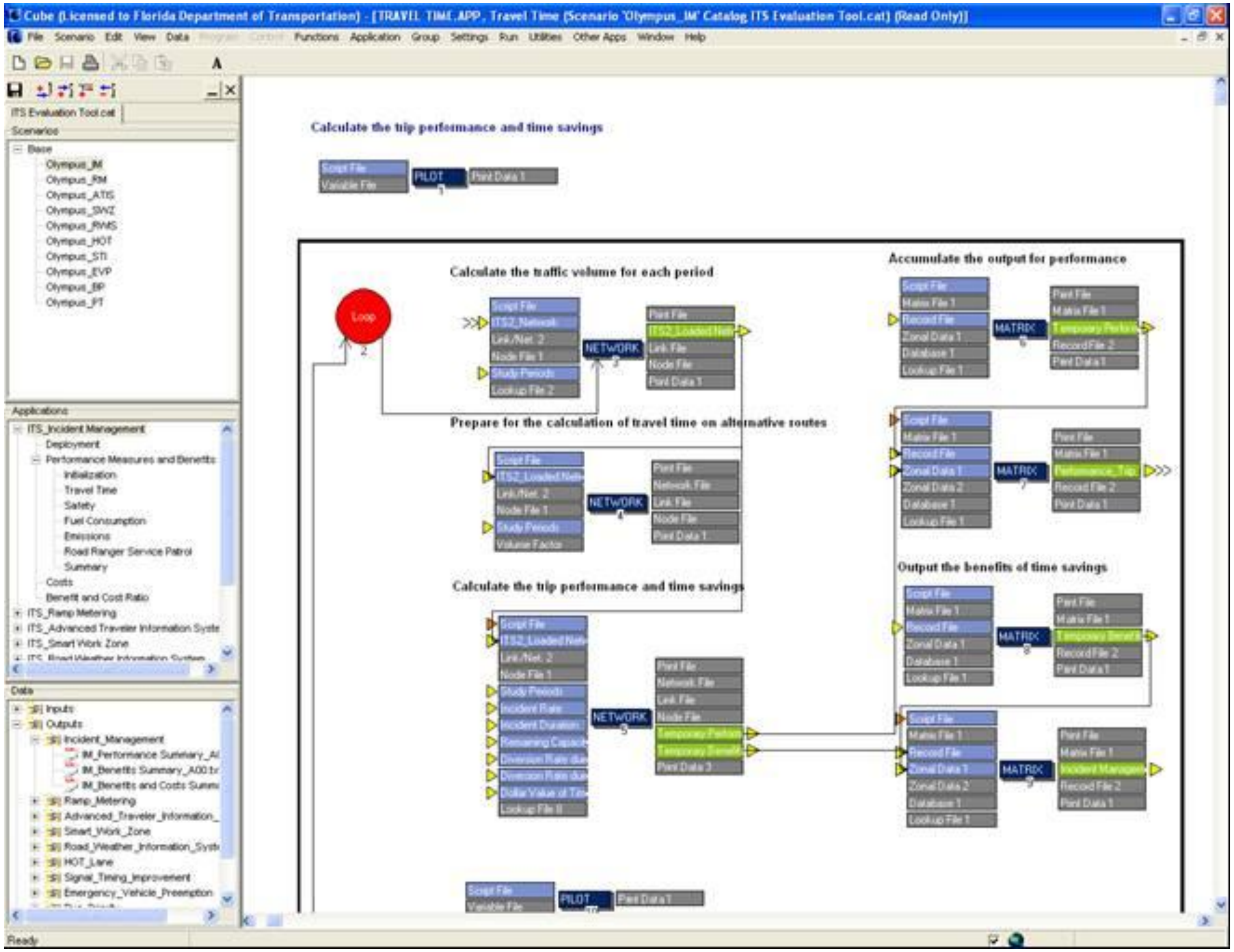


Figure 6-2 Travel Time Estimation in Incident Management

6.7.2 User Interface

The user interface was generally described in Section 5.0. This section describes the deployment parameter, analysis parameters, and impact factors that are specific user inputs to incident management and driver information dissemination evaluations (see Figure 6-3 and Figure 6-4). Some of these parameters are further discussed after the list is presented.

- Deployment parameters: These are parameters related to the implementation and operation of ITS deployment. For incident management, it includes:
    - Type of incident management (six combinations for incident management with or without DMS and HAR)
    - Information types provided by DMS or HAR (either descriptive information or detailed descriptive information). This affects the percentage of drivers diverting in response to messages.
    - Deployment locations: In this field, the user can indicate the links within the coverage of incident management by adding one new attribute IM and assign the value of 1 to this attribute. Note that only the freeway links are included in the evaluation of incident management systems.
- Analysis parameters: these inputs include parameters that are required to analyze the performance of a system with and without ITS. For incident management systems, they include
    - Incident information including frequency, duration, and remaining capacity as a function of blocked lanes and total number of lanes
- Impact factors: for incident management, these include
    - Diversion rate due to DMS and HAR for the two types of information considered in this study (see Figure 6-8 for default value)
    - Percentage of fatalities that are shifted to injury due to faster response (default = 21 percent)
    - Percentage reduction in total crash rate due to reduction in secondary incidents (default = 2.8 percent)
    - Average trip length on the mainline (default = 8 miles)
    - Average trip length on the alternative route (default = 8.2 miles)
    - Percentage of diverted vehicles using freeways as opposite to arterials when diverting to alternative routes (default = 0 percent)
    - Monetary benefits of service patrols

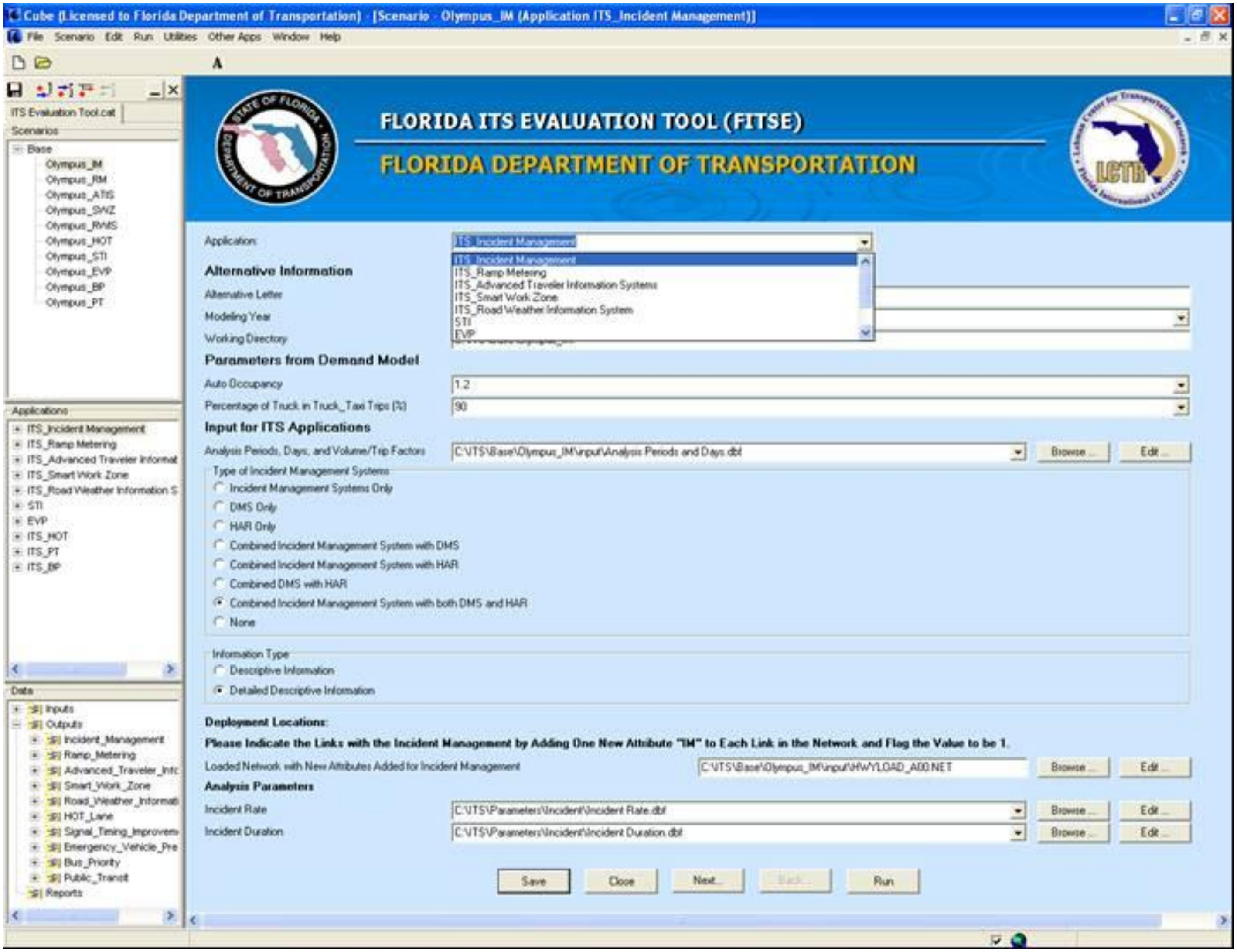


Figure 6-3 Interface to Input Parameters that are Specific to Incident Management

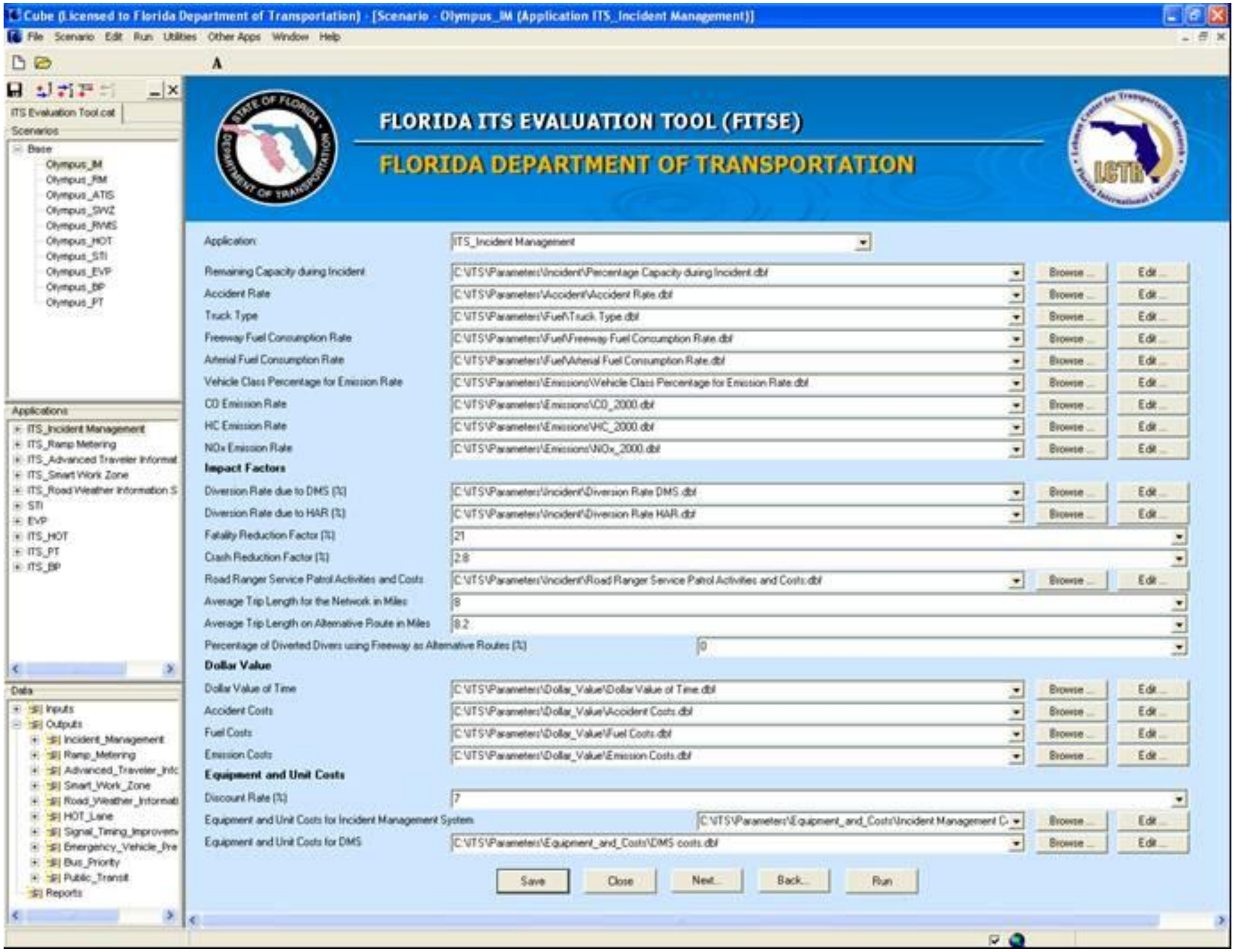


Figure 6-4 Interface to Inputs Additional Parameters that are Specific to Incident Management

Below are more detailed descriptions of some of the inputs listed above:

- **Deployment locations:** As shown in Figure 6-5, a new attribute IM is introduced to flag each link in the network as having or not having incident management deployment. The user can indicate that a link has incident management by clicking on the link and changing the attribute value of the IM parameter to 1. The user can also modify this attribute for a group of links (such as all freeway links) by specifying the appropriate criteria in the link attribute calculation feature of Cube.

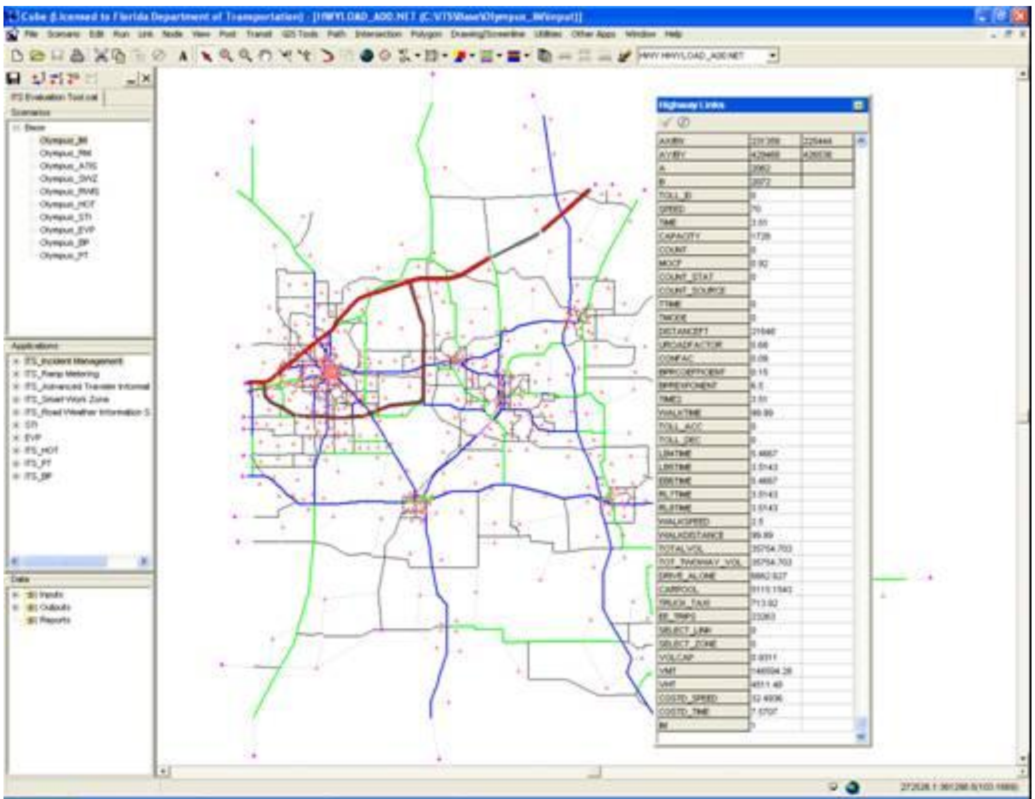


Figure 6-5 Deployment Locations

Incident rate inputs: Figure 6-6 shows the incident rate inputs, which include the types of incident (INCI_TYPE) and the corresponding incident rates (INCI_RATE) in units of number of incidents per million-vehicle-mile traveled (MVMT).

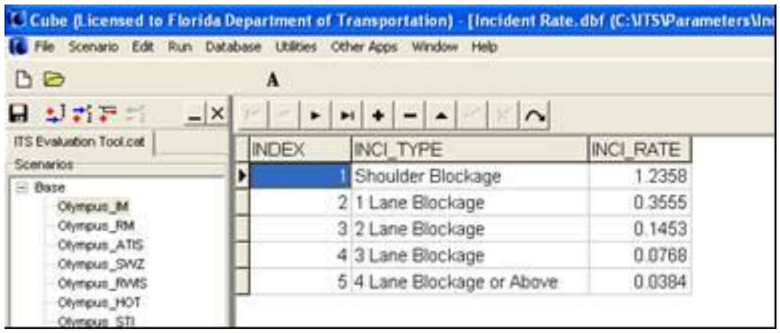


Figure 6-6 Incident Rate Inputs

- **Incident duration inputs:** Figure 6-7 depicts the incident duration inputs. The "INCI_TYPE" column describes the type of incidents. The "NO_ITS" and "WITH_ITS" columns correspond to the incident duration in units of minutes without incident management and with incident management, respectively.

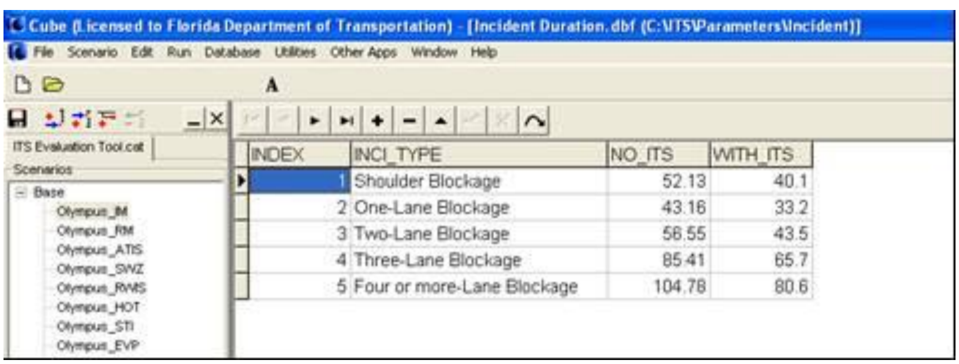
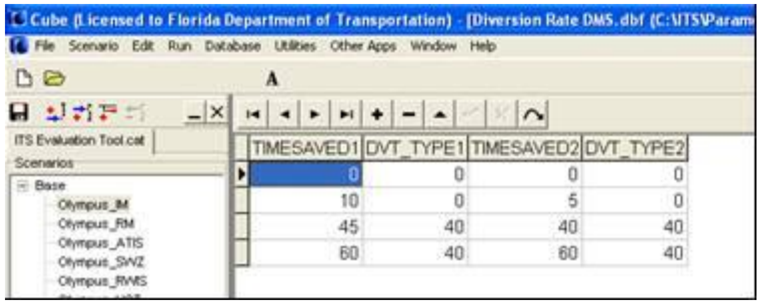


Figure 6-7 Incident Duration

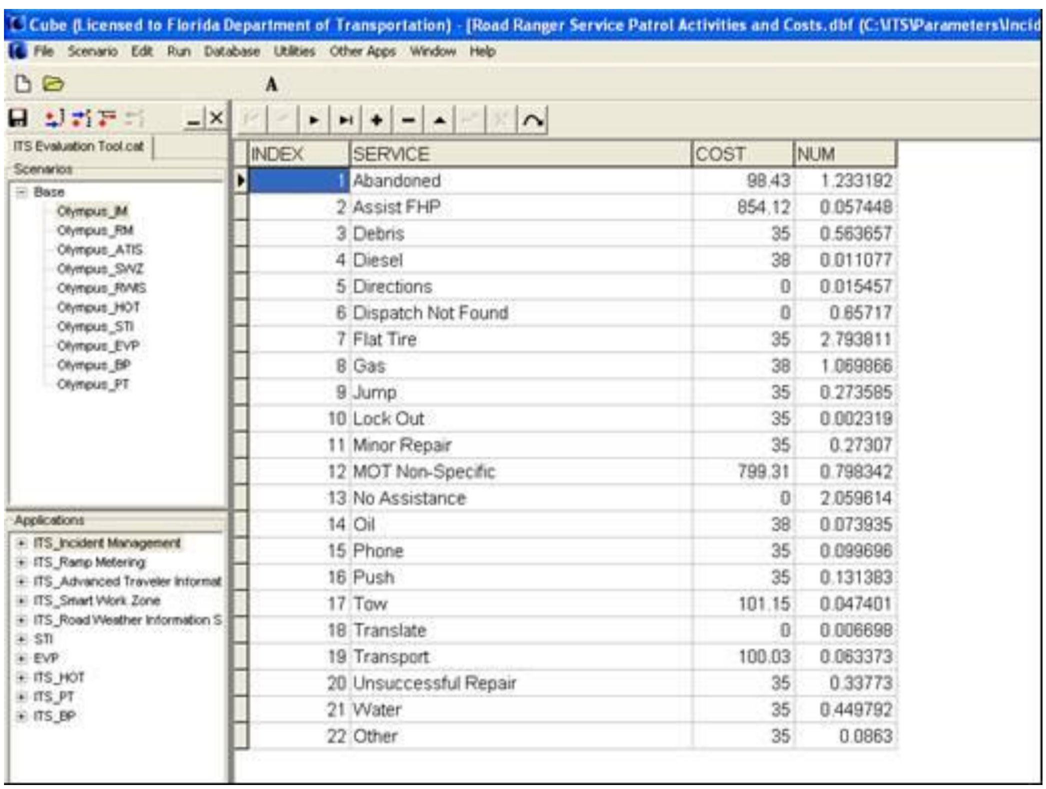
Diversion rate due to DMS or HAR: Figure 6-8 illustrates the format of the inputs that specify the diversion rates due to DMS or HAR. The TIMESAVED1 column denotes the estimated time saving in minutes when providing general descriptive traffic information (such as incident ahead) by DMS or HAR. DVT_TYPE1 is the corresponding diversion rate in percentage. TIMESAVED2 and DVT_TYPE2 are the estimated time savings in minutes and percentage diversion rate, respectively, when detailed traffic information is provided.



TIMESAVED1	DVT_TYPE1	TIMESAVED2	DVT_TYPE2
0	0	0	0
10	0	5	0
45	40	40	40
60	40	60	40

Figure 6-8 Diversion Rate

- **Service Patrol Monetary Benefits:** Figure 6-9 shows the inputs to specify the road ranger service patrol monetary benefits. The "SERVICE" column lists all the activities performed by service patrols. The "COST" column includes the cost incurred by motorists or FHP if a given service is not provided by the service patrol. The "NUM" column presents estimates of the rates of these activities per million vehicle-miles traveled based on FDOT District 4 data.



INDEX	SERVICE	COST	NUM
1	Abandoned	98.43	1.233192
2	Assist FHP	854.12	0.057448
3	Debris	35	0.563657
4	Diesel	38	0.011077
5	Directions	0	0.015457
6	Dispatch Not Found	0	0.65717
7	Flat Tire	35	2.793811
8	Gas	38	1.069866
9	Jump	35	0.273585
10	Lock Out	35	0.002319
11	Minor Repair	35	0.27307
12	MOT Non-Specific	799.31	0.798342
13	No Assistance	0	2.059614
14	Oil	38	0.073935
15	Phone	35	0.099696
16	Push	35	0.131383
17	Tow	101.15	0.047401
18	Translate	0	0.006698
19	Transport	100.03	0.063373
20	Unsuccessful Repair	35	0.33773
21	Water	35	0.449792
22	Other	35	0.0863

Figure 6-9 Road Ranger Service Patrol Monetary Benefit Inputs

- **Equipment and unit cost inputs:** Figure 6-10 displays an example of the inputs to specify the required equipment and the associated unit costs. The "NAME" column includes the required equipment, and "PER" specifies the quantity of the equipment (e.g., one traffic detector per half mile). "PER_IN_NUM" includes this same information in numerical format for use by the program. “LIFETIME” indicates the equipment lifetime. “CAPI_COST” includes the capital costs and “OM_COST” includes the operation and maintenance costs. The “SHARE” column includes the percentages of the total costs of the equipment that should be assigned to incident management, considering that they could be shared with other ITS applications.

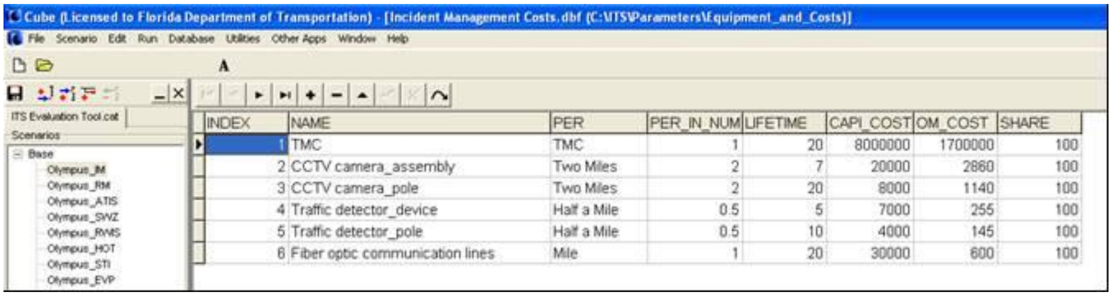


Figure 6-10 Equipment and Unit Costs for Incident Management

6.7.3 Output Interface

As described in Chapter 5, three standard output files are generated for incident management: 1) performance summary, 2) benefits summary, and 3) benefits and costs summary. The three displays are organized under the incident management output category in the data window. Figure 6-11 presents an example of performance summary display. As shown in this figure, the annual delay, number of accidents, fuel consumption, emissions, and road rangers with or without incident management are reported. Figure 6-12 displays the economic annual benefits (in dollars) by period due to travel time, safety, fuel consumption, and emissions benefits. The total benefits, average annual costs, and benefit/cost ratio for the scenario under investigation are reported in the benefits and costs summary file, as shown in Figure 6-13.

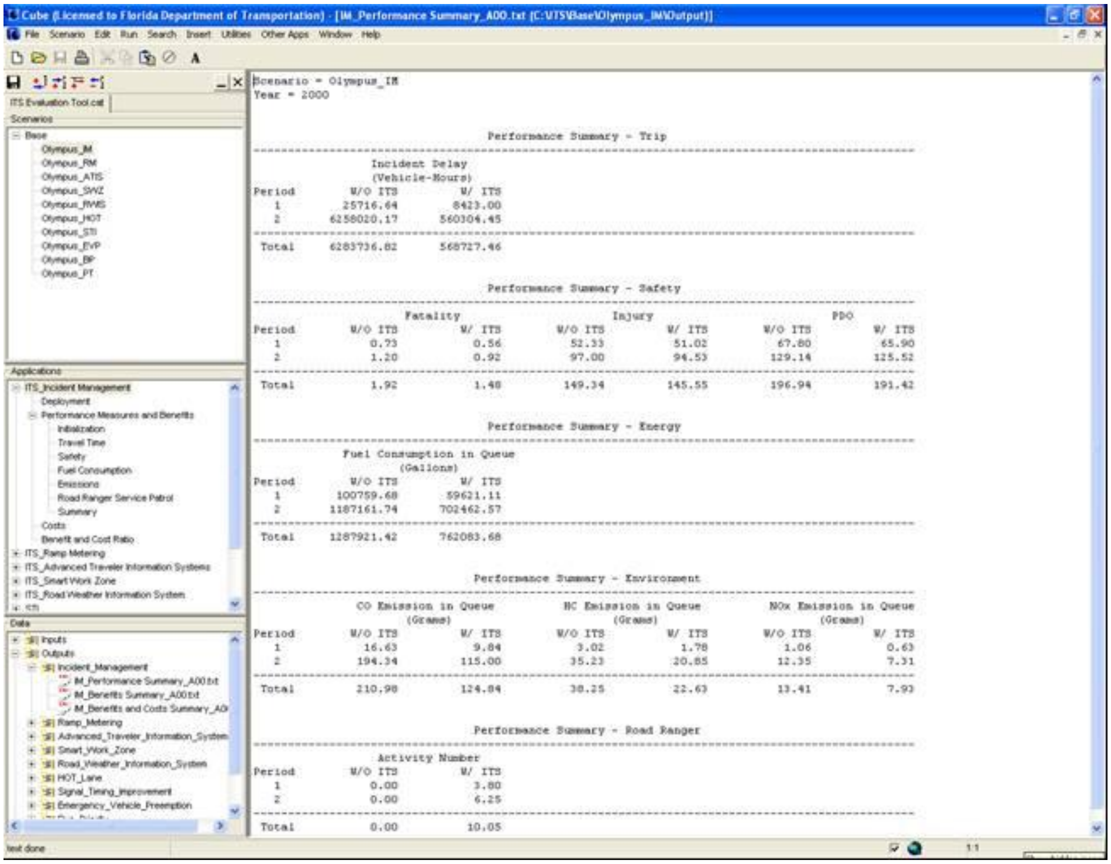


Figure 6-11 Performance Summary Output for Incident Management

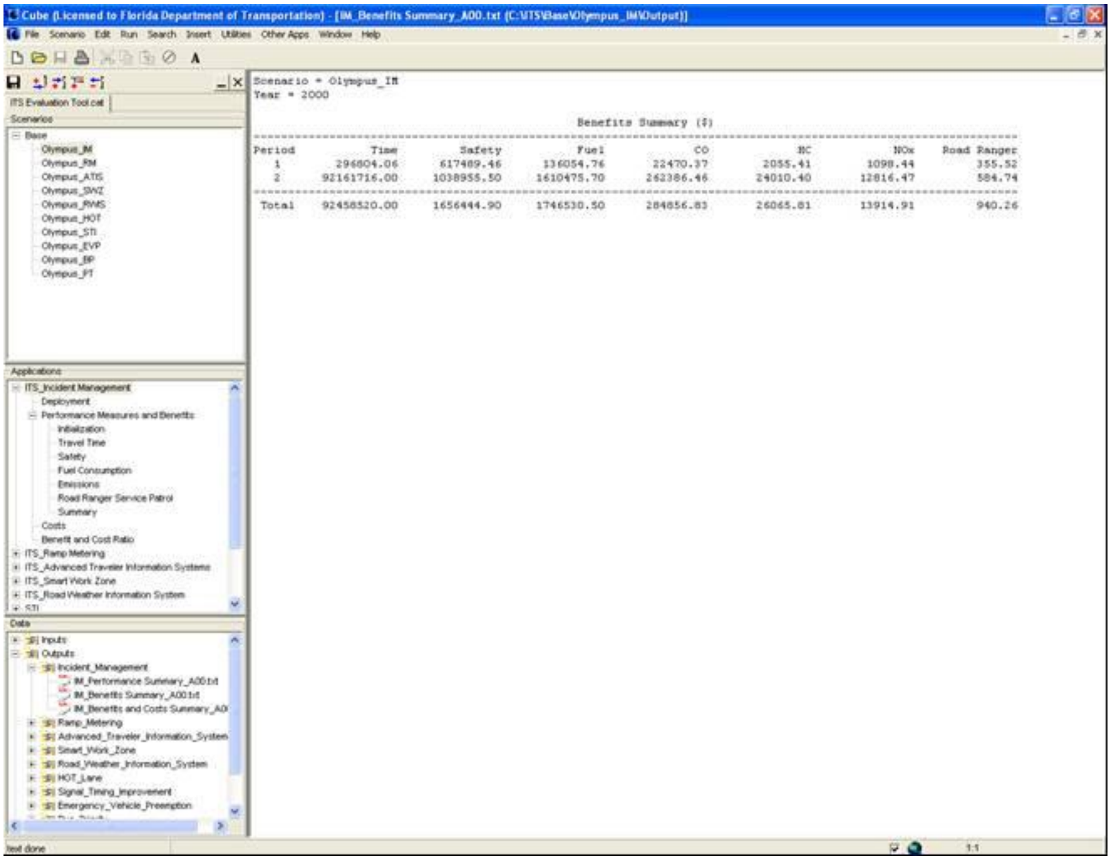


Figure 6-12 Benefits Summary Output for Incident Management

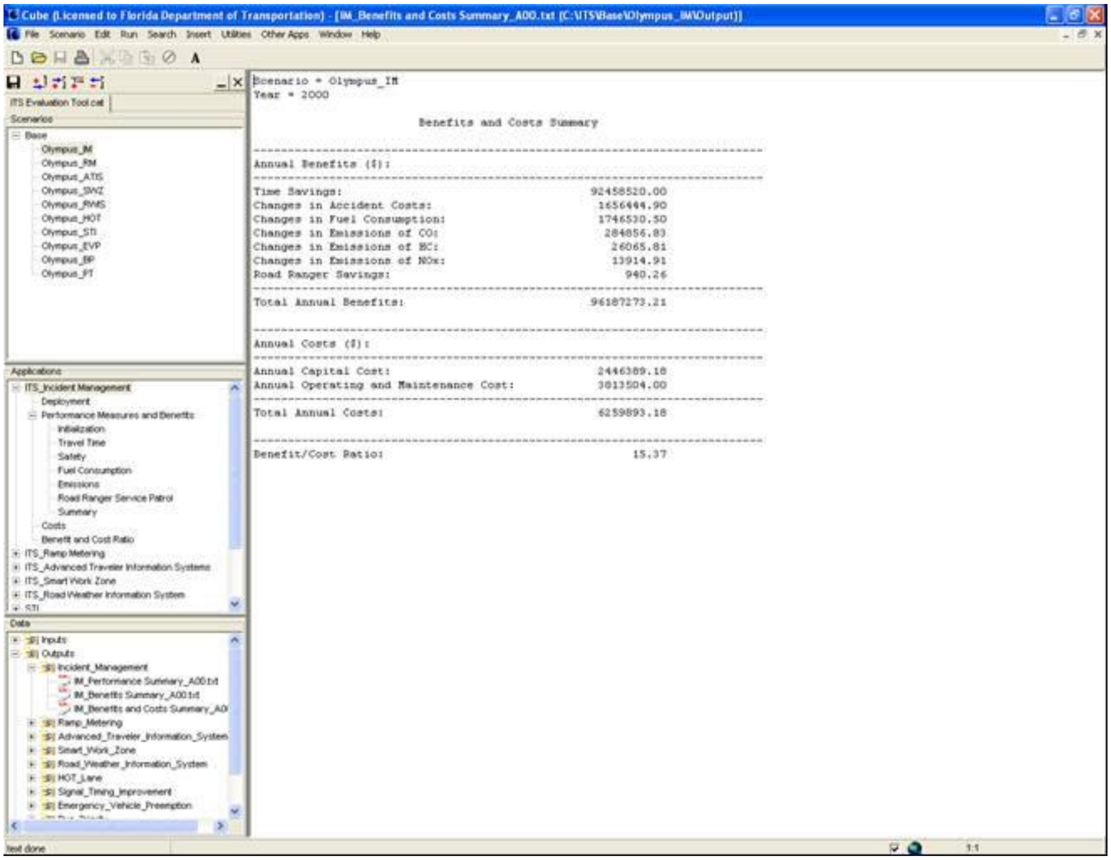


Figure 6-13 Benefits and Cost Summary Output for Incident Management

7 Ramp Metering

Metering is a method of regulating the flow rate at which traffic can enter a freeway to improve safety and mobility. Ramp metering uses traffic signals at freeway on-ramps to control the rate that vehicles enter the freeway. The signals can be set for different metering rates to optimize freeway flow and minimize congestion. Traffic responsive ramp metering algorithms and real-time data from mainline loop detectors are often used for more effective systems.

7.1 Previous Approaches to Evaluation

7.1.1 IDAS Methodology

IDAS considers three types of ramp metering deployments: 1) preset ramp metering, 2) traffic actuated or traffic-responsive ramp metering, and 3) centrally controlled ramp metering. IDAS assumes that with these ITS components, the capacity at the affected links (typically, from the freeway link at the upstream of the first metered ramp to the downstream freeway link of the last metered ramp) will increase 9.5 percent for the pre-set ramp metering and 13.5 percent for the other two types of ramp metering. The capacities at the metered ramp are assumed to decrease 33 percent for the pre-set ramp metering, 28 percent for traffic actuated ramp metering, and 27 percent for the centrally controlled ramp metering. Another assumed impact of ramp metering is that it reduces the accident rate by 30 percent at the affected freeway and ramps.

Based on the assumed changes in freeway and on-ramp capacities, the traffic is reassigned to the network and the program evaluates the benefits including the reductions in travel time, accidents, emissions, and fuel consumption.

7.1.2 ITSOAM

ITSOAM considers the effect of ramp metering on delay, accidents, and emissions. In the delay reduction module, the tool considers the reduction in freeway travel time, increase in arterial travel time, and increase in ramp delay. The travel time saved on freeways is obtained by increasing the average freeway speed by 25 percent, and the travel time increase on parallel arterial is calculated by decreasing the speed by 12.5 percent. It is assumed that the ramp metering is only activated during the peak period of the weekday. Based on the study by Kang and Gillen,[69] the software assumes that 5 percent of the vehicles divert from the ramp to arterials. The user can ask the tool to

[69] Kang, S., and D. Gillen. “Assessing the Benefits and Costs of Intelligent Transportation Systems: Ramp Meters.” California PATH Program, Institute of Transportation Studies, University of California, Berkeley, CA, Working paper UCB-ITS-PRR-99-19, 1999.

consider the daily increase in ramp delay with a default of 1 minute per vehicle. The safety benefits are calculated by applying a reduction factor of 25 percent to the accident rate. The emissions and fuel consumption on freeway, ramp and even arterial, are considered. The emission factors and fuel consumptions depends on the average speed. The idle emissions on the ramp is estimated by multiplying the emission factors for speed of 2.5 mph by 2.5, and the idle fuel consumption is found by multiplying the fuel consumption for speed of 5.0 mph by 5.0.

7.1.3 Breakeven Analysis Using SCRITS[70]

A breakeven analysis was applied to study the benefits and costs of ramp metering. The analysis considered the required accident reduction, freeway speed increase, and delays on ramps as well as on parallel arterials. The study found that in order to obtain a positive benefit/cost ratio, a relatively small freeway speed increase was needed.

7.1.4 Twin City Ramp Metering Evaluation

The ramp metering application deployed and operated by Minnesota DOT in the Twin Cities Metropolitan Region is one of the most extensive applications in the nation with over 430 ramp meters. The Twin Cities ramp metering system was subject to an extensive evaluation when the meters were turned off for a six-week period for evaluation of the impacts of the ramp metering.[71] An extensive planning and policy review effort followed to modify the region's metering system to better balance the needs of system operators and regional travelers. Several performance measures were used to evaluate the ramp metering system. Below is a summary of the results:

- Throughput: Traffic volumes on the freeway mainline were observed to decrease by nine percent when the meters were shut down. The volumes on the parallel arterials did not appreciably change when the meters were shut down.
- Travel Time: Freeway speeds were reduced by 14 percent, or 11.9 km/h (7.4 mi/h), when the meters were shut down, resulting in greater travel times that more than offset the elimination of ramp queue delays. The travel times on the parallel arterials did not appreciably change when the meters were shut down.
- Travel Time Reliability: Travel times were nearly twice as unpredictable when the meters were shut down.
- Safety: Crashes on freeways and ramp segments increased by 26 percent when the meters were shut down.

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[70] Zhong-Ren P., E. Beimborn and M. Neluheni, "A Framework for the Evaluation of the Benefits of Intelligent Transportations Systems," Prepared for the Wisconsin Department of Transportation, November 30, 2000.

[71] "Twin Cities Ramp Meter Evaluation -Final Report," Prepared for Minnesota Department of Transportation. Cambridge Systematics, Inc. February 2001.

- Benefit/Cost Analysis: The ramp metering system was estimated to produce approximately $40 million in benefits to the Twin Cities region. These benefits outweighed the costs of the ramp metering system by a ratio of 15 to 1.

7.1.5 Wisconsin Evaluation of Ramp Metering

This study[72] discussed the propensity of Wisconsin drivers to divert from the freeway when faced with the need to wait for vehicles ahead of them at a ramp meter. Modal diversion (such as shifts to carpools or transit) was not analyzed and there was no evidence in the collected data that temporal diversion (sometimes referred to as peak spreading) occurred in the study corridor. Traffic counts indicated that diversion occurred between the freeway and parallel arterials, although not all times and not all locations were impacted equally. Statistically significant diversions away from US 45 occurred when and where traffic volumes were heaviest and ramp queues were longest. The data also revealed that diversion between on-ramps along US 45 occurred in response to queuing at ramps. From the questionnaire responses from those Wisconsin drivers who said that they regularly encountered ramp meters, it was found that 72 percent of drivers are aware of alternate routes and 65 percent have a good idea of the travel time the alternate route would take. Only 24 percent of drivers said they would divert if the ramp were half full, but 62 percent said they would divert if the ramp were nearly full and 82 percent said they would divert if the ramp were over flowing. However, field observations indicated that the traffic diverted from the freeway was almost always less than 10 percent. This agreed with the results from another study [73] that found that no more than 5-10 percent of vehicles would be diverted when ramp meters are turned on.

During the afternoon peak period, the study found a substantial reduction in vehicle-hours of travel due to increases in travel speeds under minimal volume changes (a 0 to 2 percent increase) was documented between Capitol Drive and Greenfield Avenue. Speeds increased by 13 percent in the segment between Capitol Drive and Burleigh Street, by 10 percent between North Avenue and Wisconsin Avenue, and by 6 percent between Blue-mound Road and Greenfield Avenue. Corridor average speed increased by only 4 percent during the afternoon peak period because no speed changes were effected on the north part of the corridor where near-free-flow speeds often existed. Although mainline vehicle hours of travel decreased by 5 percent, when ramp delay was taken into account, the total vehicle hours of travel decreased by 2 percent.

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[72] Horowitz, A., J. Wu and J. P. Duarte, “Evaluation of Ramp Meter Effectiveness for Wisconsin Freeways, A Milwaukee Case Study: Part 1, Diversion and Simulation,” Wisconsin Department of Transportation, Council on Research, University of Wisconsin, Milwaukee, Madison, MI, 2004.

[73] Kang, S. and D. Gillen, “Assessing the Benefits and Costs Of Intelligent Transportation Systems: Ramp Meters, California Partners For Advanced Transit And Highways Research Report,” UCB-ITS-PRR-99-19, July 1999.

The crash rate was 298 crashes per 100 MVM of travel without ramp metering and 260 crashes per 100 MVM of travel with the new ramp meters. Operation of the new ramp meters in conjunction with improved ramp merging geometrics and mainline pavement resurfacing resulted in an overall 13 percent crash rate reduction (16 percent reduction in the number of crashes) during ramp metering hours.

7.1.6 Additional Studies

A study of the benefits of ramp metering in Washington State reported the following benefits:[74]

- Over 30 percent reduction in rear-end and sideswipe collisions.
- An 8.2 percent reduction in freeway mainline congestion.

While diversion is essential in order to achieve positive benefits, studies on the impacts of ramp metering on parallel arterials conducted in Los Angeles, Denver, Seattle, Detroit, and other cities show that no significant diversion from the freeway to parallel arterials occurred in any of these locations.[75]

Haj-Salem and Papageorgiou[76] conducted a field study of the corridor traffic pattern and the impact of ramp metering in the southern part of the Périphérique Corridor in Paris. The Périphérique Corridor consisted of two parallel rings around the city of Paris that were connected by a number of radial roads with corresponding on-ramps and off-ramps. The impacts associated with the application of ramp metering resulted in a reduction of 8.1 percent and 6.9 percent in total travel time for the two parallel rings including the ramps. Overall system travel time was reduced by 6.1 percent. The benefits of ramp metering were even higher under non-recurrent congestion. The total travel times were reduced by 10.8 percent, 11.6 percent, and 10 percent for the system and the two parallel rings, respectively.

7.1.7 Assessment

When evaluating ramp metering, ITSOAM and SCRITS apply fixed percentages of improvements to various performance measures of the freeway and deterioration in

[74] Taylor, C. and D. Meldrum, "Evaluation of a Fuzzy Logic Ramp Metering Algorithm: A Comparative Study Between Three Ramp Metering Algorithms Used in the Greater Seattle Area," Produced by the Washington State Transportation Center (TRAC) for the Washington State Department of Transportation, February 2000.

[75] Piotrowicz, G. and J. Robinson, "Ramp Metering Status in North America," Update. Report No. DOT-T-95-17, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., June 1995.

[76] Haj-Salem, H. and M. Papageorgiou, "Ramp Metering Impact On Urban Corridor Traffic: Field Results," Transportation Research, A. Vol. 29A, No. 4, 1995, pp. 303-319.

ramp and arterial performance measures due to the implementations of ramp metering. The problem with this approach is that the improvement in freeway operations and deterioration in ramp and arterial operations are functions of the traffic demand levels in the system.

The IDAS approach does not use fixed percentages of changes in travel time and delays due to ramp metering improvements. Rather, it uses fixed percentages of changes in freeway and on-ramp throughput and afterwards uses the traffic assignment module to reassign the vehicular trips based on the new capacity. The travel times after the implementation of ramp metering is calculated based on these demands using the relationship between the V/C ratio and the travel time for the highway facility type under consideration. Some issues associated with this approach include:

- Using fixed percentages for changes in throughputs based on results reported in previous studies, without considering the mainline and on-ramp traffic flows may not produce acceptable results. In addition, previous studies have reported a wide range of percentage changes in freeway throughput due to ramp metering. A review by the IDAS program developers of the potential increase in freeway mainline throughputs found that the values reported in previous studies for the improvement in throughput vary from 4 percent to 62 percent for pre-set ramp metering and from 2 percent to 100 percent for traffic responsive ramp metering. Using an average value based on these wide ranges may not produce good results.

- As stated above, IDAS assumes that the freeway capacity always increases by 9.5 percent to 13.5 percent due to ramp metering. In reality, the observed increase in throughput due to ramp metering is due to the reduced probability of breakdown conditions. Previous studies showed that the throughput during breakdown condition (queue discharge rate) is about 1,800-1,900 veh/hr/lane and the throughput for non-breakdown conditions, is 2,200 veh/hr/lane. The probability of breakdown depends on the level of traffic on the freeway and the on-ramps.

- As stated above, IDAS calculates the reductions in on-ramp throughput due to ramp metering by using percentage reductions, estimated based on previous studies. However, these reductions are expected to be functions of the average ramp metering rates required to keep the merge area below the breakdown level of traffic flow. In addition, calculating the resulting travel time/delay on the ramps using the BPR V/C-speed relationship rather than queuing analysis (which is more appropriate for interrupted flow conditions, as is the case with metered ramps) is expected to underestimate the delays on the ramps.

- After adjusting the freeway mainline and ramp maximum throughput values, IDAS runs the assignment module to determine the number of vehicles that divert from/to alternative routes. The evidence regarding how much traffic actually diverts due to ramp metering is conflicting. Some studies reported that ramp metering has no significant impacts on diversion to alternative routes, as discussed in the above subsections. Thus, using an equilibrium assignment based on travel time, as is done in IDAS, may not reflect the actual behaviors of motorists.

7.2 Requirement Analysis

The followings are the requirements identified for ramp metering in the developed Tool:

- The Tool shall allow users to identify the freeway mainline links affected by ramp metering, an alternative route, and the metered freeway ramps.
- The Tool shall calculate the travel time with and without ramp metering on the freeway mainline.
    - The travel time improvements shall consider the increase in throughput due to the reduction in the probability of breakdown.
- The Tool shall calculate the delays on the on-ramps due to ramp metering.
    - The Tool shall consider the increase in delay for on-ramps as a function of the expected metering rate due to ramp metering when calculating on-ramp delays.
    - The Tool shall consider the reduction in the ramp capacity and the diversion to alternative routes when calculating on-ramp delays.
- The evaluation methodology shall calculate the increase in delay on the alternative routes due to diversion.
    - The user shall be able to identify the percentage of travelers diverting to arterial streets and freeways for consideration in delay calculations.
- The tool will calculate the safety improvement due to the ramp metering based on a default reduction in accident rate.
    - The user shall be able to change the default reduction in accident rate due to ramp metering.
    - The changes in accident frequencies shall be calculated as a function of the changes in accident rate and the change in demands due to ramp metering.
- The Tool shall calculate the fuel consumption and environmental impacts of ramp metering.

7.3 Benefit Evaluation Methodology

As stated in Section 7.2, *the Tool must be able to calculate the travel time with and without ramp metering on the freeway mainline. This travel time improvements must consider the increase in throughput due to the reduction in the probability of breakdown.*

IDAS software assumes a 9.5 percent to 13.5 percent increase in freeway capacity and a 27 percent to 33 percent decrease in capacity of metered ramps. No impacts on alternative routes are considered. ITSOAM applies a 25 percent increase to speed on affected freeways and a 12.5 percent decrease for alternative arterials. In addition, ITSOAM assumes a delay of one minute per vehicle for vehicles on metered ramps. These approaches ignore the fact that the improvement in freeway operations and deterioration in ramp and arterial operations are functions of traffic demand levels in the system and the metering rates. The ramp evaluation methodology used in this study considers these effects. Below is a description of the methodology.

To calculate the mainline throughput benefits due to ramp metering, assume that the freeway throughput in a small time period t to be $C(t)$ is the weighted average of throughput without breakdown C and throughput with breakdown C_{bc}. The mathematical expression is shown as follows:

$$C(t) = \rho(t)C_{bd} + (1-\rho(t)) \times C \tag{7-1}$$

where ρ is the probability of breakdown during the observed time period t, which is calculated by using the expression developed by Kühne, et al.[77] as follows:

$$\rho(t) = \frac{t}{\tau_{bd}}\left(\frac{\tau_\infty - \tau_0}{4\tau_0} n_0\right)^{1/2}(1-\Delta)\Delta^{3/4}]\exp[-\frac{\tau_\infty - \tau_0}{4\tau_0} n_0 \frac{(1-\Delta)^2}{(1+\Delta^{1/2})^2}] \tag{7-2}$$

where τ_{bd} denotes the characteristic time of breakdown. τ_0 and τ_∞ are the characteristic time for a vehicle leaving a small vehicle cluster and a large cluster, respectively. n_0 represents the characteristic size of vehicle clusters in number of vehicles. Δ is dimensionless freeway demand that is defined as follows:

$$\Delta = \frac{V - V_{c1}}{V_{c2} - V_{c1}} \tag{7-3}$$

where V represents the current traffic volume. V_{c1} is the critical traffic volume at which the traffic jam emerges, and V_{c2} are the critical traffic volume at which on traffic jam can exist. By fitting with the field data, the following parameter values were found:

$$n_0 = 20$$

$$\frac{\tau_\infty - \tau_0}{\tau_0} n_0 = 25$$

[77] Kühne, R., R. Mahnke, I. Lubashevsky and J. Kaupužs, "Probabilistic Description of Traffic Breakdown," In *Physical Review E., Vol. 65*, 2002.

$$\tau_{bd} = 2.5$$
$$V_{c1} = 1200$$
$$V_{c2} = 3400$$

Since the accumulative probability of breakdown may be less than 1 or may exceed 1 during the analysis period, the freeway throughput for the scenario without ramp metering can be estimated as follows:

$$Cave = \frac{C + C(T)}{2},\ \rho(T) \le 1 \tag{7-4}$$

$$Cave = (\frac{C + C_{bd}}{2})\frac{t_{bd}}{T} + (1 - \frac{t_{bd}}{T})C_{bd},\ \rho(T) > 1 \tag{7-5}$$

where t_{bd} represents the time that the accumulative probability of breakdown reaches 1. For the scenario with ramp metering, it is assumed that the application of ramp metering significantly reduces the probability of breakdown, and the freeway throughput is equal to the capacity without breakdown.

Another stated requirement in Section 7.2 that *the Tool shall calculate the delays on the on-ramps due to ramp metering taking into consideration the expected metering rate for the on-ramps.*

To consider the impacts of ramp metering on the ramp delays, a localized metering strategy is assumed to simplify the calculation of metering rates. In this strategy, a ramp is metered such that the volume/capacity ratio of downstream freeway link is less than a value that can be specified by the user. The default value is one. The resulted metering rate is limited to the range of 240-1200 vph for single lane and 400-1700 vph for two-lane ramps to account for the minimum and maximum headway that can be actually achieved.[78] Once the ramp-metering rate is determined, the traffic volumes on the downstream freeway links can be adjusted to reflect the new on-ramp throughputs.

Another requirement of ramp metering evaluation is *to calculate the increase in delay on the alternative routes due to diversion.*

In addition to the ramp metering impacts mentioned above, the model assumes that 5 percent of vehicles divert to the alternative routes with the deployment of ramp metering. The volumes diverted from the on-ramps are added to the volumes on the alternative routes and the increase in travel times on the alternative routes are calculated. The changes in alternative route speeds are calculated using the regionally

[78]"Ramp Management and Control Handbook," FHWA, USDOT, Report No. FHWA-HOP-06-083, January 2006

calibrated BPR curves and based on the assumption that the free flow speed, capacity, and volume on the alternative route are equal to the average values of these variables for the region for the facility type of the alternative route. The user can specify what percentage of the traffic diverts to freeway versus signalized arterials, which will be considered in the calculations.

The requirements presented in Section 7.3 also state that *the Tool shall calculate the safety improvement due to the ramp metering based on a default reduction in accident rate that the user can change.*

In this project, 25 percent of crashes at the affected freeway link as well as metered ramps are reduced due to the relatively smooth merge. Based on the improved speed, the benefits of fuel savings and emission reductions can also be estimated using the modules described in Chapter 3 of this document.

7.4 Costs

Based on the ramp metering design study in Arizona referenced previously, the ramp location costs can be estimated to vary between $54,000 and $64,000. This cost includes the combined costs of the ramp metering assembly, signal displays, controller, wiring, as well as the mobilization and MOT required during the installation. An additional cost of $6,500 is required for detection.

The Florida-specific defaults project mentioned above recommends the use of default values ranging from $60,000 to $80,000, with an additional detection cost of $2,500 for each detected lane. The project also recommends that the maintenance cost be set at $8,000 per year. An additional TMC cost needs to be added as appropriate to reflect the additional operation at the TMC.

7.5 Implementation

The evaluation methodology of ramp metering is implemented as one of the applications in the Cube catalog “ITS Evaluation Tool.” By selecting this application, the user can identify the ITS deployment to be evaluated as ramp metering, as shown in Figure 7-1.

7.5.1 Modeling Structure

The modeling structure for ramp metering consists of four modules as described in Chapter 5. Figure 7-2 presents the procedure to evaluate the traffic conditions for each period in the base scenario (with no ramp metering), while Figure 7-3 illustrates the modeling procedures to evaluate the traffic conditions for each period with ramp metering. Figure 7-4 further displays the steps for the evaluation of time savings due to ramp metering. For detailed implementation procedures, users are referred to the implemented catalog in Cube software.

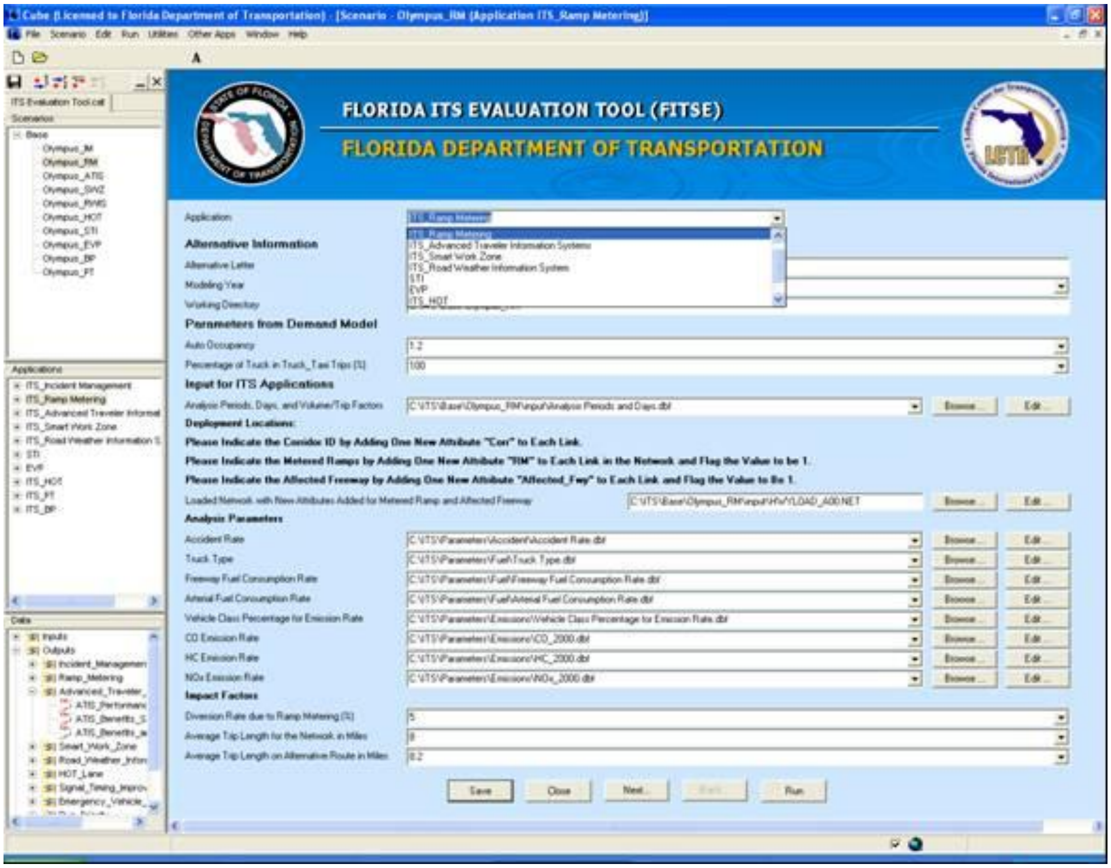


Figure 7-1 Selection of ITS Deployment Type

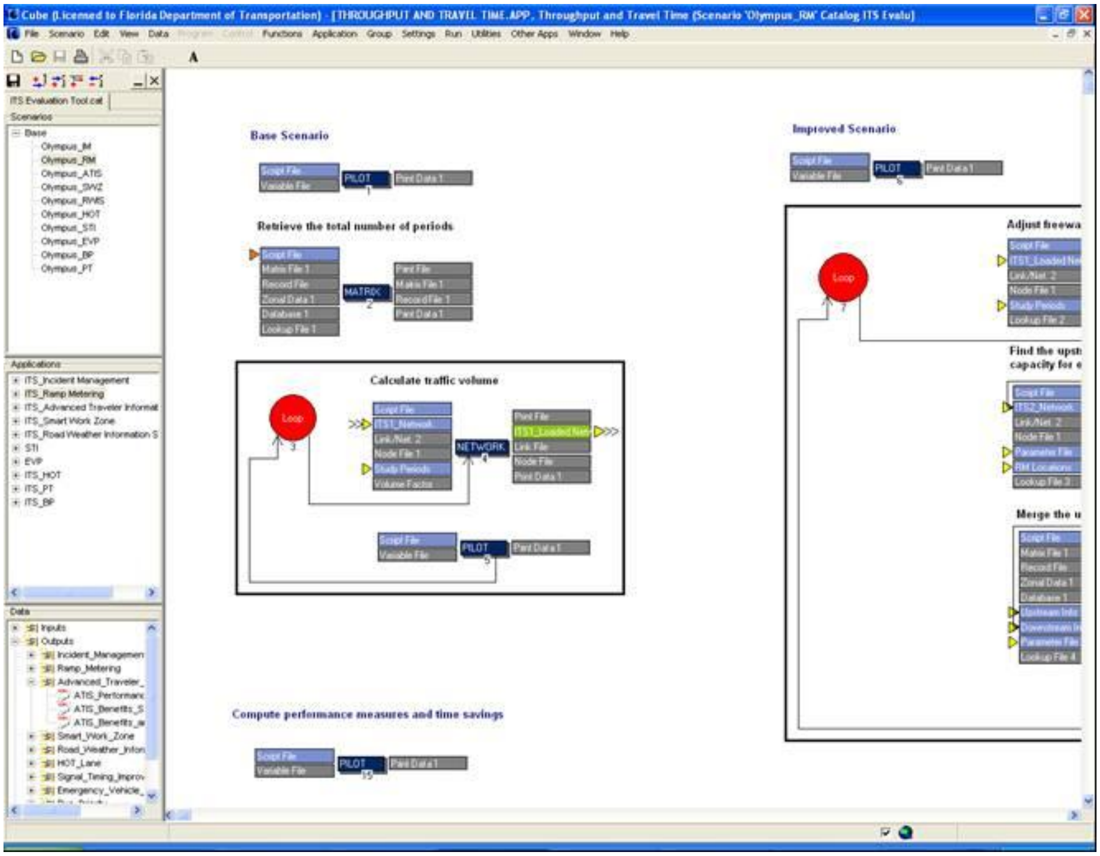


Figure 7-2 Procedure to Evaluate Traffic Conditions With No Ramp Metering

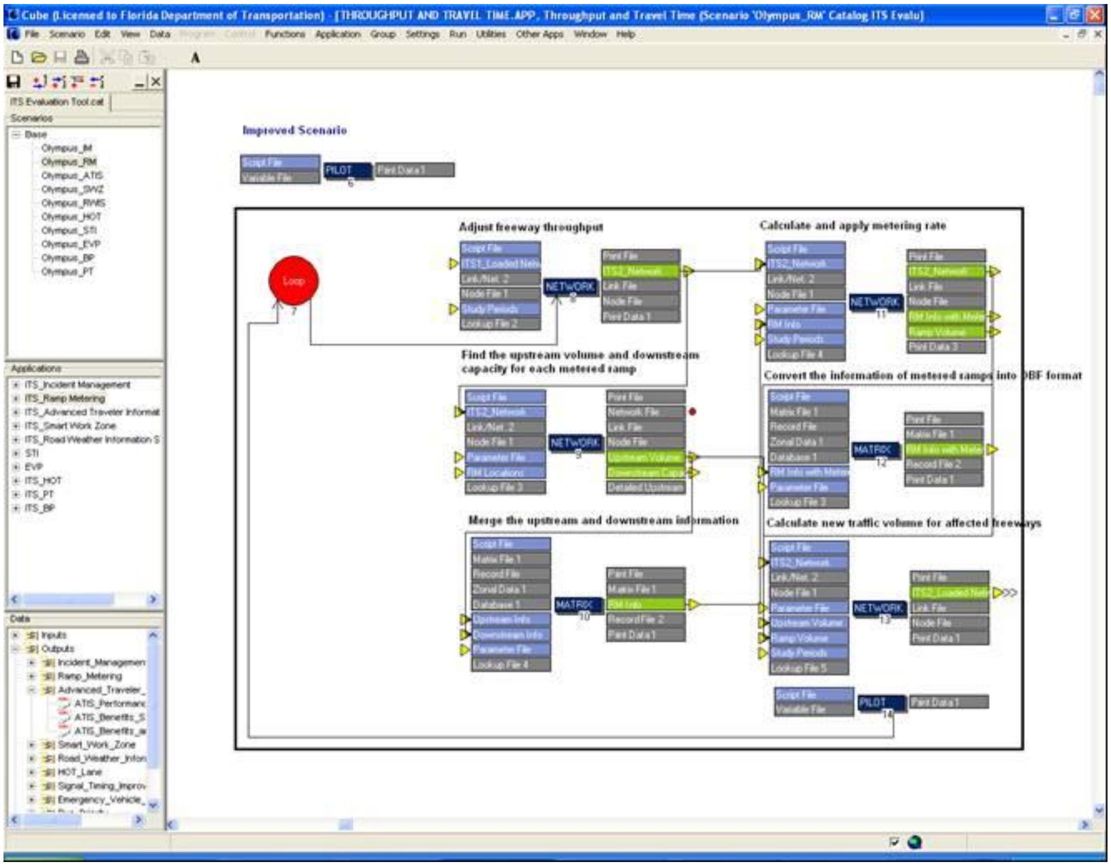


Figure 7-3 Procedure to Evaluate Traffic Conditions With Ramp Metering

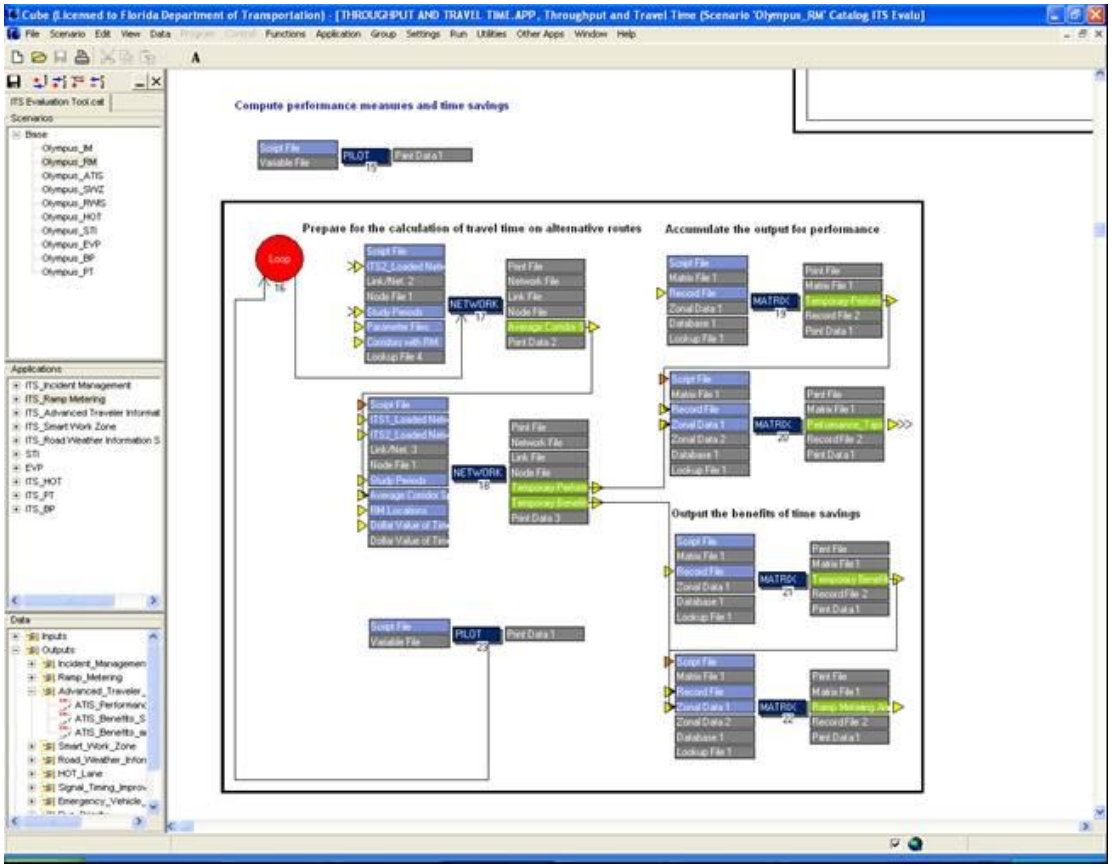


Figure 7-4 Procedure to Evaluate Time Savings Due To Ramp Metering

7.5.2 User Interface

The user interface required to analyze ramp metering require the input of general parameters that were discussed in Chapter 5. This section presents a discussion of the parameters that are specific to the evaluation of ramp metering.

- Deployment parameters
  - Deployment locations: as shown in Figure 7-5, the user needs to identify three categories of links affecting ramp metering by adding three attributes: a new attribute "Corr" to indicate the corridor number (to specify a part of the freeway mainline as one ramp metering implementation for the purpose of evaluation), a new attribute "RM" for metered ramps, and a new attribute "Affected_Fwy" for affected freeway links. The value of 1 for an attribute indicate that the link belong to the associated category.

- Impact factors including
  - Diversion rate due to ramp metering (defaults = 5 percent)
  - Crash rate reduction factor (defaults = 25 percent)
  - Average trip length on the mainline (defaults = 8 miles)
  - Average trip length on the alternative route (defaults = 8.2 miles)
  - Percentage of diverted vehicles using freeways (defaults = 0 percent)

Below is a more detailed explanation regarding some important input.

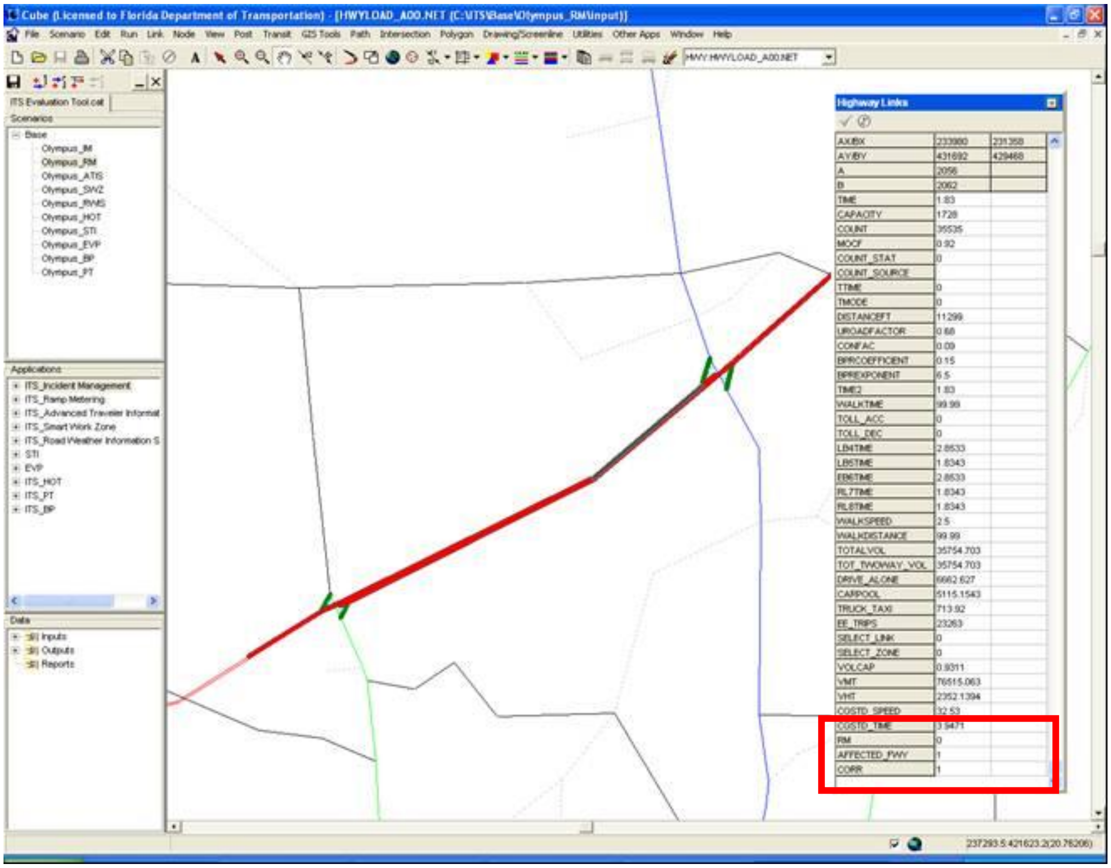
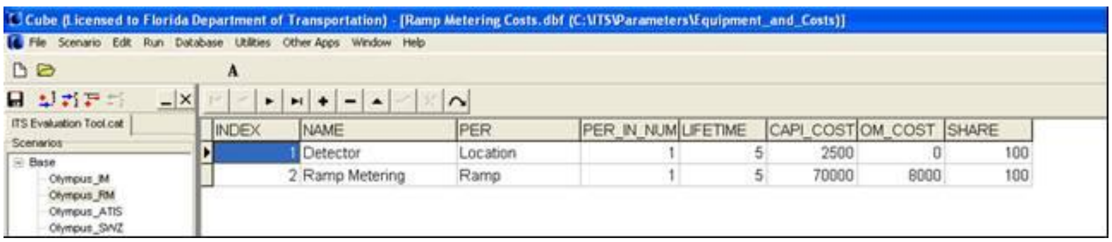


Figure 7-5 Ramp Metering Deployment Location Interface

Figure 7-6 displays the input file for ramp metering. The detector assembly and ramp metering assembly are identified as an example of needed data. As shown in this figure, "NAME" describes the equipment required and "PER" describes the units for the equipment (e.g., one per location or one per ramp). "PER_IN_NUM" is the units expressed as the numeric value for the convenience of calculation. "LIFETIME" indicates the equipment lifetime. "CAPI_COST" and "OM_COST" are the capital costs and operating and maintenance costs, respectively. The "SHARE" column includes the percentage of total costs spent on ramp metering when sharing these equipment with other ITS applications.



INDEX	NAME	PER	PER_IN_NUM	LIFETIME	CAPI_COST	OM_COST	SHARE
1	Detector	Location	1	5	2500	0	100
2	Ramp Metering	Ramp	1	5	70000	8000	100

Figure 7-6 Equipment and Unit Costs for Ramp Metering

7.5.3 Output Interface

As with other ITS deployments, three standard output files are generated for ramp metering: 1) performance summary, 2) benefits summary, and 3) benefits and costs summary. These three files are organized under the output category (ramp metering) in the data window. Figure 7-7 presents an example of the performance summary display. As shown in this figure, the vehicle-hours traveled, number of accidents, fuel consumption, and emissions for those links affected by ramp metering with or without ramp metering are reported in this file. Figure 7-8 displays the economic annual benefits of time savings, safety, fuel consumption, emission benefits, etc. for each period. The total benefits, average annual costs, and benefit/cost ratio for the scenario under investigation are reported in the benefits and costs summary file, as shown in Figure 7-9.

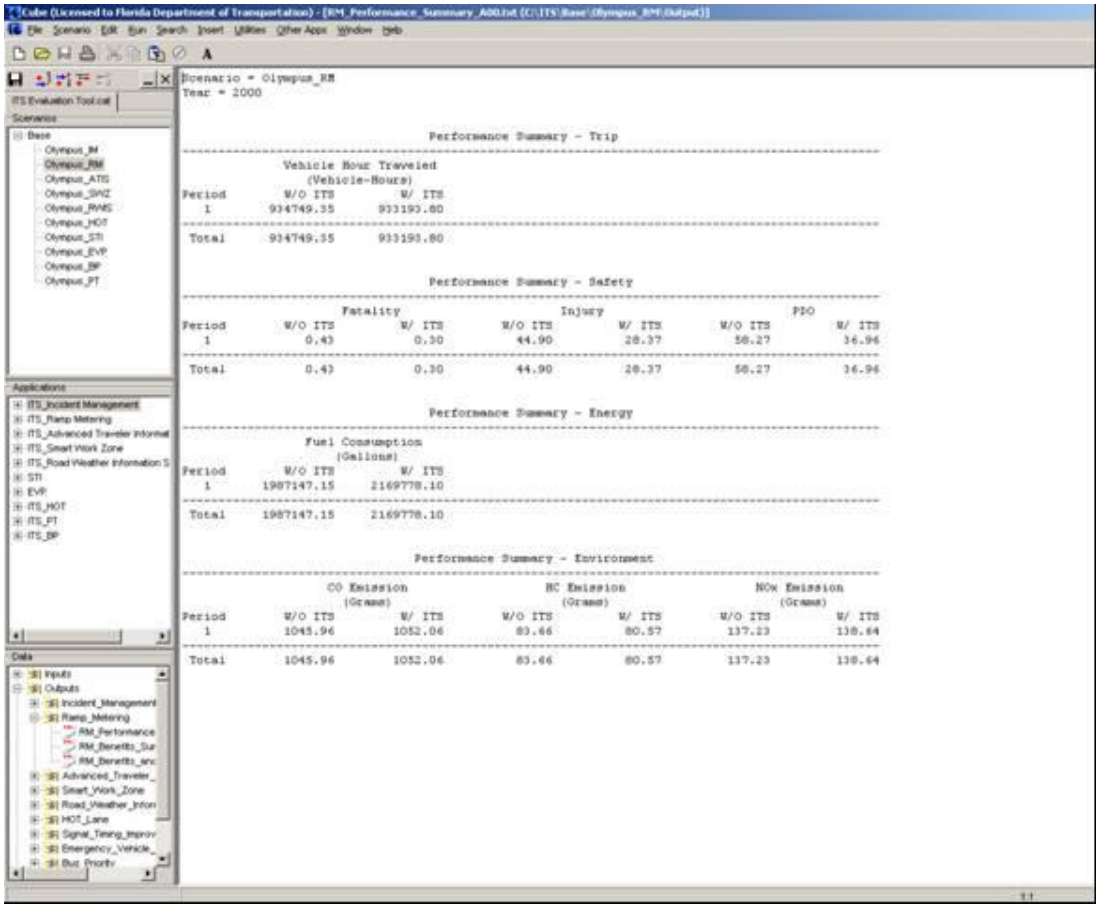


Figure 7-7 Performance Summary Output for Ramp Metering

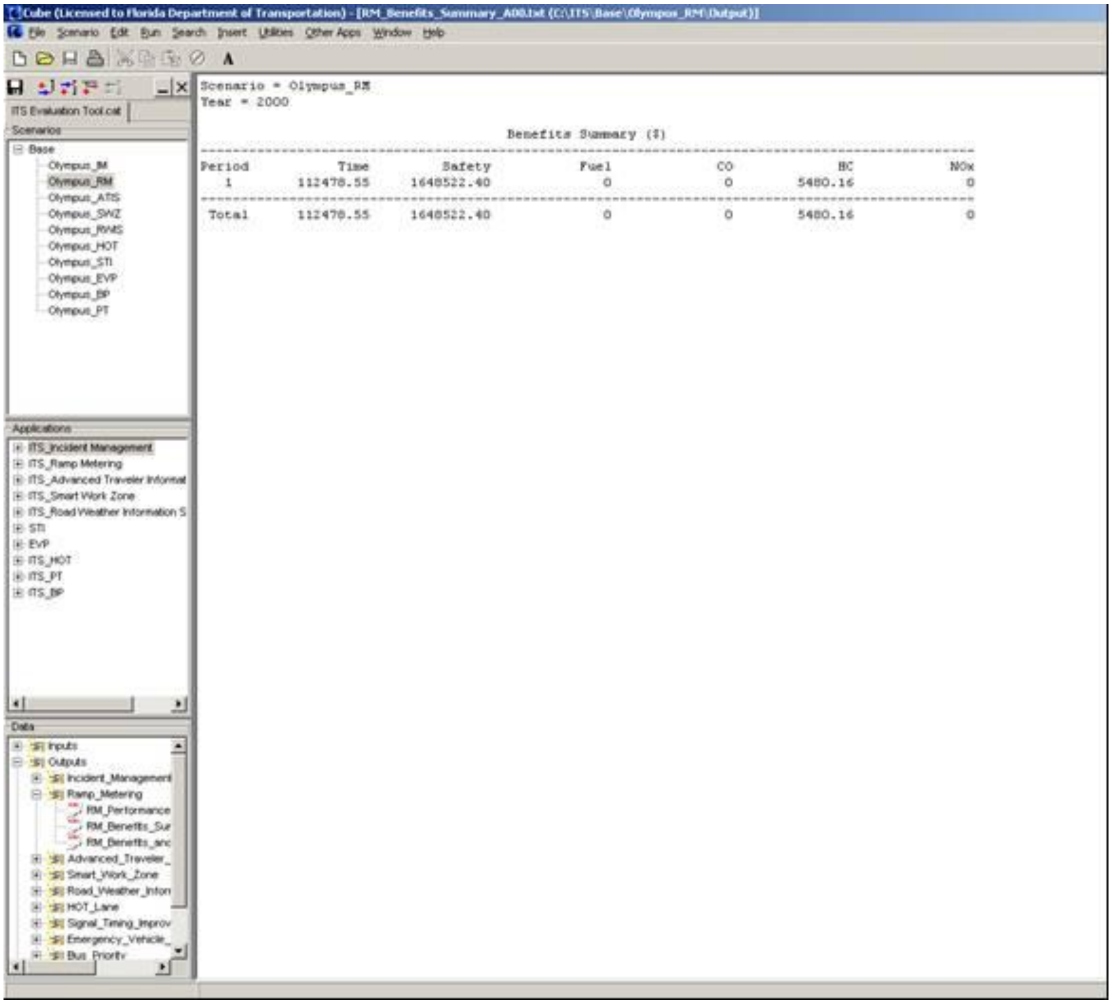


Figure 7-8 Benefits Summary Output for Ramp Metering

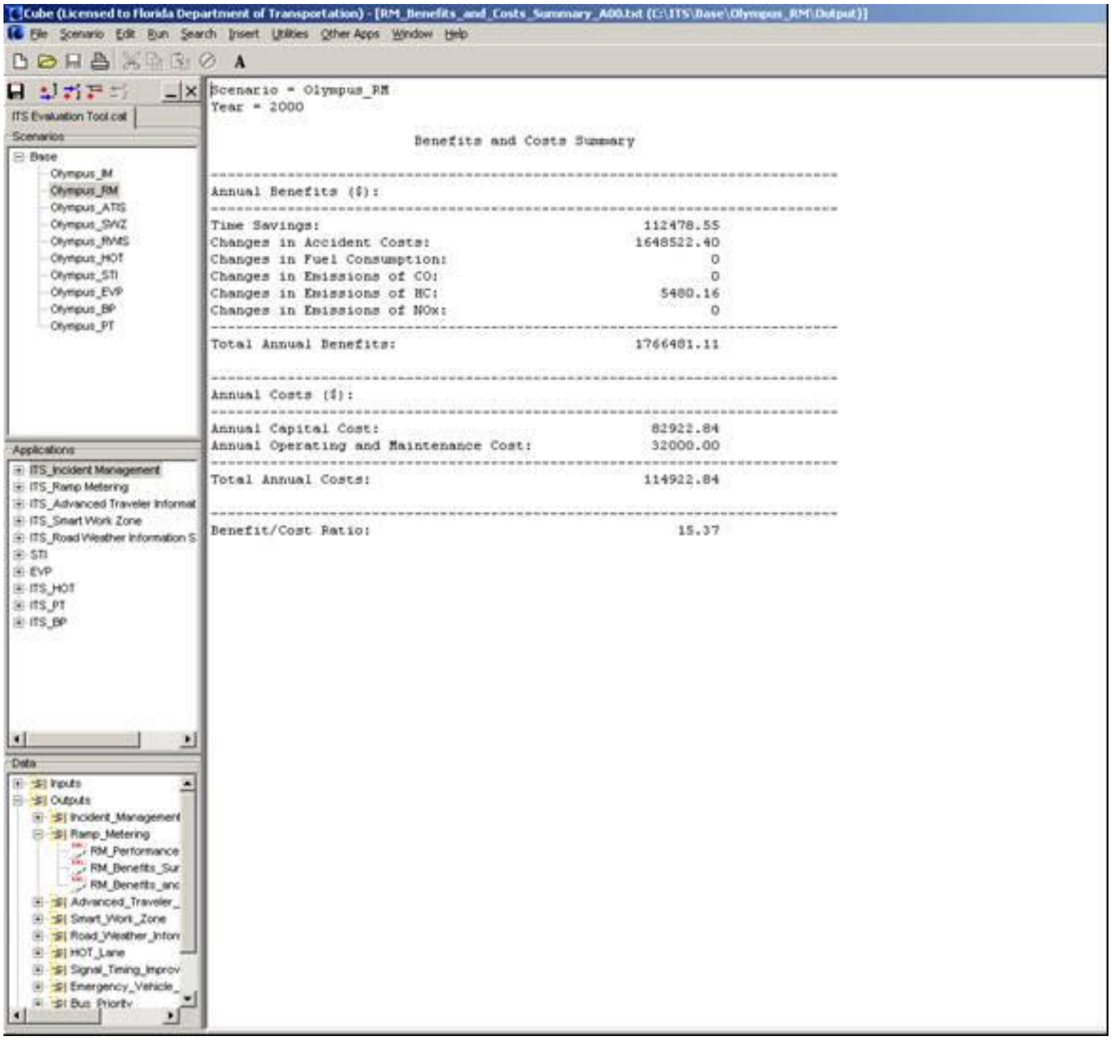


Figure 7-9 Benefit and Cost Summary Output for Ramp Metering

8 Managed Lanes

Managed lanes are developed in order to maximize the use of existing highway capacity. Managed lanes are limited-access lanes; normally, a barrier separates the highway lanes. They could be tool lanes with no high occupancy vehicle (HOV) preference or High Occupancy Tool (HOT) lanes that provide free or reduced cost access to qualifying HOVs, while providing access to other paying vehicles not meeting passenger occupancy requirements. By using price and/or occupancy restrictions to manage the number of vehicles traveling on them, managed lanes maintain volumes consistent with acceptable levels of service even during peak travel periods. For the purposes of this report, two types of managed lanes are considered: express toll lanes with no HOV preference and HOT lanes.

Most managed lanes are created within existing general-purpose highway facilities and offer potential users the choice of using general-purpose lanes or paying for good traveling conditions on the toll lanes. Toll lanes utilize sophisticated electronic toll collection and traffic information systems and may utilize variable, real-time toll pricing. Information on price levels and travel conditions can be communicated to motorists via dynamic message signs (DMS), providing potential users with the facts they need in order to decide whether or not to utilize the managed lanes or the parallel general-purpose lanes that may be congested during peak periods. Traffic is monitored to ensure that the service on the toll lanes is maintained at an acceptable level of service (e.g., LOS C or LOS D). These lanes may be created through new capacity construction or conversion of existing lanes. Conversion of existing HOV lanes to HOT operation is a common approach.

8.1 Previous Approaches to Evaluation

Managed lanes are not included in IDAS or ITSOAM assessments. This section presents a review of three topics related to managed lanes that are of interest to this study: 1) the approaches used to evaluate and optimize the operation of managed lanes, 2) the willingness of travelers to pay for using the managed lanes, and 3) the benefits of managed lanes reported in previous studies.

8.1.1 Evaluation and Optimization Approaches

This section discusses a number of approaches used for managed lane assessments.

The Equilibrium Assignment Approach

Brunk and Middleton[79] used an equilibrium relationship to evaluate the impact of different alternatives of implementing HOT lanes on the demands on the managed lanes and general used lanes. The following equation was used:

$$V_T*[C_T+(D_T/60*T_v)] = (V-V_T)*(D_F/60*T_V) \qquad (8\text{-}1)$$

Where:

V= Volume of total vehicle demand;
V_T = Volume of tolled vehicles;
D_T = Delay of tolled vehicles in minutes per unit distance;
D_F = Delay of free vehicles in minutes per unit distance
C_T = cost of toll in dollars per unit distance; and
T_V= present value of time in dollars per vehicle-hour ($11.94/person-hour was used).

Five corridors in Dallas, TX area were tested for different toll lane options using the above equations.

In another example of using equilibrium assignment for this purpose, HOT and HOV lane alternatives were compared using the Sacramento region demand model.[80] The study estimated that the HOV economic benefit is negative (-$55,033) and that the dollar value of the HOT lane benefits is $297,477.

Li and Govind[81] presented a toll evaluation model find a HOT lane toll that accomplishes different objectives:

- It can be used to determine a toll that ensures a minimum speed on the toll lanes and/or on the general purpose (GP) lanes.
- It can also be used to select a toll that will maximize the flow on the toll lanes and/or on the GP lanes.

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[79] Brunk, J.C. and M.D. Middleton, “Incorporating Toll-Lane and High-Occupancy Toll-Lane Effects into the Dallas System Planning Methodology,” In Transportation Research Record: Journal of the transportation Research Board, No.1659, TRB, National Research Council, Washington, D.C., 1999, pp 105-110.

[80] Rodier. C.J. and R.A. Johnston, “A comparison of High Occupancy Vehicle, High Occupancy Toll and Truck Only Lanes in the Sacramento Region,” Presented at 80th Annual Meeting of the Transportation Research Board, Washington, D.C., 2002.

[81] Li, J. and S. Govind, “An Optimization Model For Assessing Pricing Strategies of Managed Lanes,” CD-ROM, Transportation Research Board, National Research Council, Washington, D.C. 2003.

The model framework begins by comparing travel times between a toll-travel managed lane and a free-travel one. The demand for the managed lane is derived at a given toll fee and time savings. As the demand for the managed lane increase, the travel speed on the managed lanes decreases, and the time savings of using the managed lane compared to the free/general purpose lanes also decreases. This change affects travelers' willingness to pay for using the managed lanes and therefore the demand for managed lanes. The model continues to iterate until it reaches an equilibrium point. The approach uses macroscopic traffic flow relationships to predict the travel time under different volumes.

The I-95 express lane between downtown Miami and I-595 in South Florida is currently being constructed. The project involves the conversion of an existing single-HOV lane in each direction to two high-occupancy toll lanes. Alternative analysis was conducted during the initial stages of the deployment. South of the Golden Glades interchange, six different project configurations and operation scenarios were tested as part of the alternatives analysis. These ranged from simple conversion of existing HOV lanes to HOT to deployment of reversible HOT lanes to construction of an elevated roadway with up to four lanes of additional high-speed traffic. All tolls would be collected electronically and demand and congestion in the managed lanes would be managed by raising or lowering toll rates depending on the time and direction of travel.

Three levels of models were developed to analyze different alternatives:

- The regional SERPM model was used to estimate total demand in the future in the I-95 corridor;
- A micro-model, using a tight window (subarea) of the SERPM model, was used to estimate the share of traffic such that could be expected to use the managed lanes versus the tool-free general purpose lanes; and
- A detailed micro simulation model was used to estimate changes in travel speeds and travel times under varying shares of traffic between the toll-free and tolled managed lanes.

The subarea trip tables used in the micro-model were initially extracted from region-wide traffic assignments at base-year (2004) levels. These trip tables were used as seed matrices in a calibration process that adjusted the trip tables to traffic volumes representing the average hourly volume (for each of the time periods) for I-95 ramps and mainlines for the analysis intervals used in the micro-model, which are smaller than those used in the regional model. The hourly traffic volume profile summarized previously was used to identify appropriate analysis intervals for use in this study. Microscopic simulation was used to better evaluate the impacts of the project on travel speeds of different segments of the freeway. Relationships between traffic demand and speed were calibrated for each link used in the micro-model based on VISSIM. These relationships were used in the market share analysis. The share of each traffic movement that the managed lane captures is based on an estimate of the assumed distribution of the value of time (VOT) also developed from the stated preference surveys. It was assumed that motorists with a VOT greater than the cost per minute saved would tend to pay for the managed lanes while those with a lower VOT would tend not to choose the lanes.

The micro-model relies on developing an equilibrium condition between the toll cost and the estimated time savings. If more traffic uses the managed lanes, less congestion is in the free lanes and the time savings is lower. Less time savings would result in less traffic choosing the managed lanes. For each toll rate level, an equilibrium point exists between the level of traffic congestion in the free lanes (time savings) and the amount of traffic willing to pay a toll to save that same amount of time. At low toll levels, there is a higher propensity to use the managed lanes and there is a lower congestion level in the free lanes. At higher toll levels, less traffic is in the managed lanes and the free lanes are more congested. A full range of toll rates was tested, from $0.05 per mile to $0.60 per mile, for each time period and travel direction. The toll rates chosen for use in the traffic and revenue analysis generally reflect those that maximize revenues for each individual time period. During certain peak periods in the 2020 and 2030 assignments, checks for capacity constraints in the managed lanes indicated a need to use higher toll rates to manage demand to maintain an acceptable level of service at one or two locations in the system. A higher range of toll rates were tested and chosen in those cases. The micro-model for each of the three trip tables was separated into five components: SOV work, SOV non-work, HOV-2 work, HOV-2 non-work, and HOV-3+. The trip tables were assigned simultaneously until an equilibrium condition was reached for that particular toll rate.

As part of the Miami I-95 project, a stated preference survey was conducted to gauge the willingness of motorists to pay for a given amount of time savings. The stated preference data from the survey were compiled into an ALOGIT dataset used to support estimation of the coefficients of a multinomial Logit-based mode-choice model and later estimation of individual coefficients for each respondent in the sample using Hierarchical Bayes estimation. The median values of time for the segments were $7.65 per hour for the peak hour work trip, $9.30 per hour for the peak hour non-work trips, $8.37 per hour for the off-peak hour work trip, and $8.06 per hour for off-peak non-work trip.

Discrete Choice Approach

McDonald and Noland[82] used a nested Logit model to evaluate the demand on HOT lanes for a hypothetical corridor. The Logit model's bottom nest is the time-of-day trip choice. This was split into 1-minute intervals relative to the desired work start

[82] McDonald, N.C., and R.B. Noland, "Simulated Travel Impacts of High Occupancy Vehicle Lane Conversion Alternatives," In Transportation Research Record: Journal of the Transportation Research Board, No.1765, TRB, National Research Council, Washington D.C. 2001, pp.1-7

time. Intervals up to 40 min early and 20 min late were used. The second level of the nest is the choice of which lane to use. The top level of the nest represents the choice of mode. The overall model structure was defined as:

$$P_n(mlt) = P_n(m/lt)\,P_n(l/t)\,P_n(t) \tag{8-2}$$

where $P_n(mlt)$ represents the probability of choosing mode m given choice of lane l given departure time choice t.

DeCorla-Souza[83] used a pivot point mode choice model incorporated into the SMITE-ML evaluation tool to estimate the impacts of the evaluation alternatives on peak period mode shares, pivoting from the estimated No-Build mode shares in the year 2020. Impedance coefficients used in the model were those calibrated for the Washington, DC metropolitan area. Three conventional Build alternatives (without tolls but with different HOV lane configurations) were evaluated in the Capital Beltway Study in comparison to the No Build alternative. In addition, three toll lane alternatives were investigated in lieu of the HOV lanes. Tolls would be charged only during peak hours (6-10 am and 3-7 pm) on the tool express lanes and would vary dynamically to ensure that traffic flows freely at all times, including the peak hour of each peak period. The study estimated that by converting two barrier-separated HOV lanes in each direction to two barrier separated toll lanes with pricing of $3 in each direction would reduce the delay by 46.16 percent. Travelers save up to 13 min each way by using the express lanes.

<u>Logit Model combined with Assignment/Simulation Approach</u>

Murray et al.[84] assessed high occupancy toll-lane usage and network performance based on a mesoscopic traffic simulation model interfaced with an unordered multinomial logit mode-choice model. The model allows prediction of high-occupancy, transit, and single occupancy vehicle modal shares, based on prevailing traffic conditions and tolls. This method is capable of predicting toll lane volumes combined with mode shift but not travel time shift. Generic level of service attributes were used in the utility expressions of the logit mode-choice model that determine whether a given vehicles is HOV, SOV, and whether the HOT lane is chosen. To facilitate the interface of the mode-choice model with the shortest path calculation,

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[83] DeCorla-Souza, P., "Evaluation of Toll Options Using Quick-Response Analysis Tools: A Case Study of the Capital Beltway," CD-ROM, Transportation Research Board, National Research Council, Washington, D.C., 2003.

[84] Murray, P.M., H.S. Mahmassani and K.F. Abdelghany, "Methodology for Assessing High-Occupancy Toll-Lane Usage and Network Performance," In Transportation Research Record: Journal of the transportation Research Board, No.1765, TRB, National Research Council, Washington, D.C., 2001, pp 8-15.

the generalized cost was expressed in units of time (minutes). The resulting systematic utility equations are:

V_{SR}= -2.169-0.04722*Generalized Cost

V_{DA}=-0.04722*Generalized Cost

V_{TR}=-0.598-0.04722*Generalized Cost (8-3)

Where:

SR= Shared Ride (HOT)
DA=Drive Alone (SOV)
TR=Transit.

The choice probabilities for each modal alternative were then obtained using the usual multinomial logit form

$$\Pr_n = \frac{\exp(V_{in})}{\sum_{j=1}^{j} \exp(V_{jn})} \tag{8-4}$$

Where:

Pr_n=probability of individual n choosing alternative i,
V_{in}= utility for alternative i,
V_{jn}= utility for alternative j,
J= set of all possible alternatives (reduced to two in this application).

An integrated modeling framework that combines the multinomial mode-choice model described above with a dynamic network traffic assignment in DYNASMART was developed and applied to the evaluation of hypothetical test scenarios in an actual network. To simulate pricing that increases as the congestion on the facility rises, the toll was obtained by multiplying the density of the link by a constant coefficient. The investigated values of the constant were 0, 0.01, 0.1 and 1.

Choi et al.[85] used a stochastic dynamic transportation network model combined with Monte Carlo simulation and the Method of Successive Averages to evaluate value pricing strategies for I-394 corridor network. They used macroscopic traffic flow

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[85] He, R.R., B. Ran and K. Choi, "Decision Support System for Value Pricing Strategies on I-394 Corridor Network," CD-ROM, Transportation Research Board, National Research Council, Washington, D.C., 2000.

relationship to predict travel time. The link travel disutility was assumed as a linear function of link travel time and monetary cost as follows:

$$du_a(t) = \alpha * t_a(t)(\min) + \beta * fee_a(t)(\$) \tag{8-5}$$

8.1.2 Operational Experience

In this section, a discussion is presented of previous experience with managed lanes with special emphasis on information that is useful to this study.

I-15 FasTrak

The I-15 FasTrak[86] involved the conversion of an underutilized preexisting, eight-mile, 2 lane HOV facility to a peak-period reversible HOT operation. The I-15 FasTrak program allows single occupancy vehicles to pay a toll ranging from $0.50 to $4.00 to use the HOT lanes, which are otherwise reserved for HOV2+ vehicles. Customer's must have a FasTrak account and transponder to use the HOT lanes. HOV2+ vehicles may use the facility at no cost.

The dynamic price levels for SOVs on the I-15 HOT lanes were initially set to maintain Level of Service C; however, the facility also operates without congestion at level of service D. The typical peak-period toll rate approaches $4.00 for use of the eight-mile facility, with a maximum toll rate of $8.00 in times of severe incidents. All HOV (2 passengers or more), buses, motorcycles, low-emission vehicles, and emergency vehicles use the facility toll-free. In 2004, 30,000 vehicles per day accessed the facility, with approximately 25 percent toll-paying SOVs. The facility generates approximately $2,000,000 annual gross revenue in 2004. The principal costs include approximately $500,000 for operations and maintenance and $1,000,000 for the subsidy of transit service in the corridor.

SR-91 Express Lanes

The SR-91 express[87] lanes are the nation's first high-occupancy/toll (HOT) lane. It is a 10-mile, four lane, HOT facility in the median of an existing highway. Toll rates on the Express Lanes vary from $0.75 to $4.75 by time of day and day of the week. Carpools with three or more passengers could use the lanes for free. Customers must have a prepaid account and transponder to use the Express Lanes. Tolls for HOV2+ vehicles are reduced by 50 percent.

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[86] Ungemah, D.H., G. Goodin, C. Toycen and M.Burris, "Examining Incentives and Preferential Treatment of Carpools in Managed Lane Facilities: A State of the Practice Review." CD-ROM, Transportation Research Board, National Research Council, Washington, D.C., 2007.

[87] "A Guide for HOT Lane Development," U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., March 2003.

Poole and Orski[88] noted that the SR-91 HOT lanes represented only 33 percent of the SR-91's capacity but were carrying 40 percent of the traffic during the busiest peak hours, at speeds of 65 mi/h versus 10 to 20 mi/h in the other lanes.

HOT Lane Review

A study by Benjamin et al.[89] reviewed projects that implemented HOT lanes in medium-sized cities and reported the results in Table 8-1.

Table 8-1 Summary of HOT Lane Projects

Existing Projects	SR-91	I-15	I-10(Katy Highway)	US290 (Northwest Freeway)
Region	Orange County, CA	SanDiego, CA	Houston, TX	Houston, TX
Authority	CalTrans	SANDAG	Houston Metro, TXDOT	Houston Metro, TxDOT
Number of Miles	10	8	13	13.5
Additional Lanes Built	4 new lanes	No	No	No
HOV Conversion	No	Yes	Yes	Yes
Name of HOT Lane Project	Express Lanes	FasTrak	QuickRide	QuickRide
Date HOT Lane Project Started	1995	1997	1998	2000
Design of HOT Lanes	2 HOT lanes in each direction fully separated in the median; only one access point at each end; functions as a pipeline	1 HOT Lane in each direction	1 lane reversible flow facility, five access points	1 lane barrier separated reversible flow facility

[88] Kockelman, K.M., and S. Kalmanje, "Credit-Based Congestion Pricing: A Policy Proposal and the Public's Response"-CD-ROM, Transportation Research Board, National Research Council, Washington, D.C., 2004.

[89] Benjamin, J., R. Sakano, B. McKinney, A. Khattak, D.A. Rodriguez and C.Gaskins, "An Analysis of Value Pricing in a Medium Sized City"-CD-ROM, Transportation Research Board, National Research Council, Washington, D.C., 2006.

Existing Projects	SR-91	I-15	I-10(Katy Highway)	US290 (Northwest Freeway)
Tolling Structure	Discounted tolls for 3+ carpools, zero emissions vehicles, motor cycles, disabled, veterans	2+ carpools ride free, SOV pay toll	2+ carpools may pay to use the lane when the 3+ HOV is in effect, no SOV	3+ carpools ride free, 2+ pay toll, SOVs never allowed
Toll Rates	$0.75 to $4.75	$0.50 to $4.00	$2.00	$2.00
Toll Collection	Fully automated must have FasTrak Transponder	Fully automated; must have FasTrak Transponder	Fully automated, Harris County Toll Road Authority QuickRide transponders	Fully automated, Harris County Toll Road Authority QuickRide transponders
Cost of Project	$134 million; private toll venture financed by CPTC	$7.96 million from FHWA Value Pricing Pilot Program		
Use of proceeds	ROI to CPTC	Transit Service in the corridor (Inland Breeze peak-period express bus)		
Expansion Plans	n/a	Extend I-15 HOT lanes, creating a 20 mile, reversible flow managed lane	Possibility of major expansion, HCTRA has offered $250 million to finance construction of Katy special use lanes	n/a

8.1.3 Willingness to Pay

In this section, a review of the surveys performed to study the willingness to pay of travelers on toll lanes. A questionnaire was distributed to commuters in an intercept survey of drivers leaving I-40 in a medium sized urban area (Greensboro, NC). The key question is whether people would travel on a managed lane for a toll, knowing that it would save 8 minutes or 15 minutes of travel time. The answers for the question were tabulated in Table 8-2 and Table 8-3 [90].

Table 8-2 Willingness to Pay for Express Lane Knowing It would Save 8 min of Travel Time [90]

Toll	Percent of respondents
Less than $0.25	57.25%
$0.25 to $1.25	39.31%
$1.26 to $2.50	3.05%
$2.51 to $4.00	0.38%
Total	100.00%

Table 8-3 Willingness to Pay for Express Lane Knowing It would Save 15 min of Travel Time[90]Error! Bookmark not defined.

Toll	Percent of respondents
Less than $0.50	52.87%
$0.50 to $2.50	43.68%
$2.51 to $5.00	3.07%
$5.01 to $8.00	0.38%
Total	100%

Zmud et al. [91] surveyed travelers on the I-394 HOT lane and reported the results in Table 8-4.

[90] Benjamin, J., R. Sakano, B. McKinney, A. Khattak, D.A. Rodriguez and C. Gaskins, "An Analysis of Value Pricing in a Medium sized city"-CD-ROM, Transportation Research Board, National Research Council, Washington, D.C., 2006.

[91] Zmud, J., M. Bradley, F. Douma and C. Simmek, "Panel Survey Evaluation of Attitudes and Willingness to pay for Tolled Facilities," Proceeding of the TRB Annual Meeting, Transportation Research Board, National Research Council, Washington, D.C., 2007.

Table 8-4 Willingness to Pay for Express Lane on I-394 HOT Lane Project[91]

Toll per one way trip	Percent of respondents	Time Savings (minutes)
$2	59%	20
	40%	15
	23%	10
	10%	5
$4	30%	20
	<10%	15 min or less

A study of Katy HOV lane (I-10) [92] reported that freeway participants received an average travel time saving of approximately 18.7 minutes in 2003 for a $2 toll. Average travel time savings on the Northwest Freeway HOT lane (US-290) was approximately 14.2 minutes in 2003. Survey respondents on both corridors indicated that they perceived approximately twice as much travel time savings (an average of 29.8 minutes) as was empirically measured.

A summary of the literature review presented above of the willingness to pay for lanes is summarized in

[92] Appaiah, J., and M.W.Burris. "QuickRide User Response to Different HOT Lane Operating Scenarios." Proceeding of the TRB Annual Meeting, Transportation Research Board, National Research Council, Washington, D.C., 2005.

Table 8-5.

Table 8-5 Percentage of Respondents Willing to Pay for Different Travel Time Savings

Travel Time Savings							
≤5 min[**][93]		8 min[*][94]		15 min[*]		>15 min[**]	
Toll	% of Respondents	Toll	% of Respondents	Toll	% of Respondents	Toll	% of Respondents
≤$2	10	$0.25	57.25	$0.5	52.87	≤$2	59
>$2	0	$1.25	39.31	$2.5	43.68	>$2	0
		$2.50	3.05	$5	3.07		
		$4.00	0.38	$8	0.38		
		>$4	0	>$8	0		

* Results of I-40 Survey
**Results of I-394 Survey

8.1.4 Assessment

In general the methods that have been used for evaluating toll lanes for planning purposes can be categorized into:

- Discrete choice models, in which the prediction of lane choice is combined with mode choice and possibly trip time choice using a multinomial logit model.
- Assignment models that assign the SOVs and HOVs to the lanes as part of the traffic assignment process. Most of the studies found in the literature have utilized macroscopic models to evaluate traffic measures during the assignment process. Microscopic and mesoscopic traffic assignment can also be used. Both static and dynamic assignment models have been used.

[**] Douma,F., and J. Zmud. “Pricing Comes to Minnesota: Baseline Attitudinal Evaluation of the I-394 HOT Lane Project.” CD-ROM. Transportation Research Board, National Research Council, Washington, D.C., 2005.

[*] Benjamin,J., R.Sakano, B.McKinney, A.Khattak, D.A.Rodriguez, C.Gaskins. “An Analysis of Value Pricing in a Medium sized city.” CD-ROM. Transportation Research Board, National Research Council, Washington, D.C., 2006

- Simulation models possibly combined with discrete choice models.

8.2 Cost

As shown in Table 8-1, the cost of managed lanes was reported to be 134 million for 10 miles when four new lanes are installed. The cost of a managed lane was estimated to be 8 million when no new lanes are installed. The total construction cost of the I-95 managed lanes between SR 112 and the Golden Glades Interchange (about 12 mile segment) is 136 million dollars. This includes converting the existing HOV lanes (one in each direction) to HOT lanes and one additional new lane in each direction. This cost is believed to be high due to the tight schedule of the project.

Based on the above, a 10 million dollar per mile will be used when the HOT lanes will include the construction of new lanes and 1.0 million per mile or converting an existing facility to managed lanes. The operation and maintenance costs will be assumed to be $150,000 per mile for converted facilities and $200,000 for facilities that have new lanes. It should be recognized that the cost of managed lane vary significantly depending on the implementation details. Thus, the analyst is encouraged to provide estimates for the specific managed lane(s) being analyzed.

8.3 Requirement Analysis

This section lists a set of requirements for the evaluation of managed lanes.

- The user shall have the ability to evaluate a combination of general purpose (GP) lanes and managed lanes.
    - The user shall be able to code managed lanes as one or more High Occupancy Toll (HOT) lane(s) or express toll lane(s) with no preferential treatment with all vehicles paying the same toll.
    - The user shall be able to select the (links) that are converted to managed lanes or add new lanes that can be specified as managed lanes.
    - The user shall be able to specify that the managed lanes are HOT lanes or Express toll lanes.
- The Tool shall be able to assess the impact of tolling strategies on the demands of the managed lanes, general use lanes, and alternative routes.
- The managed lane evaluation shall utilize HOV and SOV trip matrices obtained from the calibrated regional demand model.
    - The Tool shall be able to assign SOV and HOV trip matrices based on the generalized costs of the links that considers both travel time and toll costs.

  - The HOV and SOV assignments shall be an equilibrium assignment.
  - The Tool shall allow the assignment on the network level or subarea level.
  - The maximum portion of the SOV assigned to the managed lane should consider the findings from previous studies that investigate the willingness of travelers to pay.
  - The Tool shall allow the user to specify the speed-demand curve used in the assignment.
- The user shall be able to define the toll for the managed lane per mile for each managed link. The model shall provide a default value based on previous studies and implemented projects.
- The user shall be able to provide the value of time in dollars per hour. The model shall provide a default value.
- The evaluation procedure shall assign the SOV and HOV demands to the network taking into consideration the specified toll and travel time on the links (the generalized costs of the links).
- The user shall be able to specify the threshold of the number of persons per vehicle for the vehicle to use the managed lane for free.
- The user shall be able to input the number of buses per hour that use the managed lanes for free.
- The Tool shall give the user the option to allow or not allow trucks on managed lanes.
- The Tool shall give the user the option to specify the maximum percentage of HOV’s and external HOV that can use the HOT lane for free, and to use the managed lane for free to reflect the registering commuter proportion, as is done in the Miami I-95 Express Lane project.
- The evaluation procedure shall produce network and corridor based performance measures of the network with or without toll lanes.
- The Tool shall be able to produce results to check the level of service on the managed lane(s) to the user such that the user can make changes to the specified tool to ensure acceptable levels of service on the managed lanes.

8.4 Methodology

The methodology used to evaluate managed lanes involves the use of equilibrium assignment to assign the SOVs and HOVs to the lanes as part of the traffic assignment process. The static assignment of Cube was used in the testing. However, any other static or dynamic traffic assignment model can also be used. The following is an overview of the assignment process:

- Initially, the HOV volumes are fixed on the links as those obtained from the traffic demand model and the SOV trip matrices are reassigned to the network considering the toll on the toll lane for SOV trips.
- The SOV trip volumes are then fixed and the HOV trip matrices are reassigned to the network considering no toll on the toll lane for HOV trips.
- The above iterative process (reassigning HOV and SOV continued until HOT lane volumes reach a equilibrium).

The flow chart of the methodology is presented in Figure 8-1. After defining the trip matrices and the managed lanes, the assignment process described above is performed. The assignment process utilizes the generalized link travel time and cost. The static Cube assignment procedure combined with the regionally calibrated BPR curves are used in the assignment but any other static or dynamic traffic assignment and demand – speed relationship can be used in the analysis. The value of time from the I-95 Managed Lane Project Survey in Southeast Florida is used as the default value in the link generalized cost calculations. However, the user can specify this value based on local conditions.

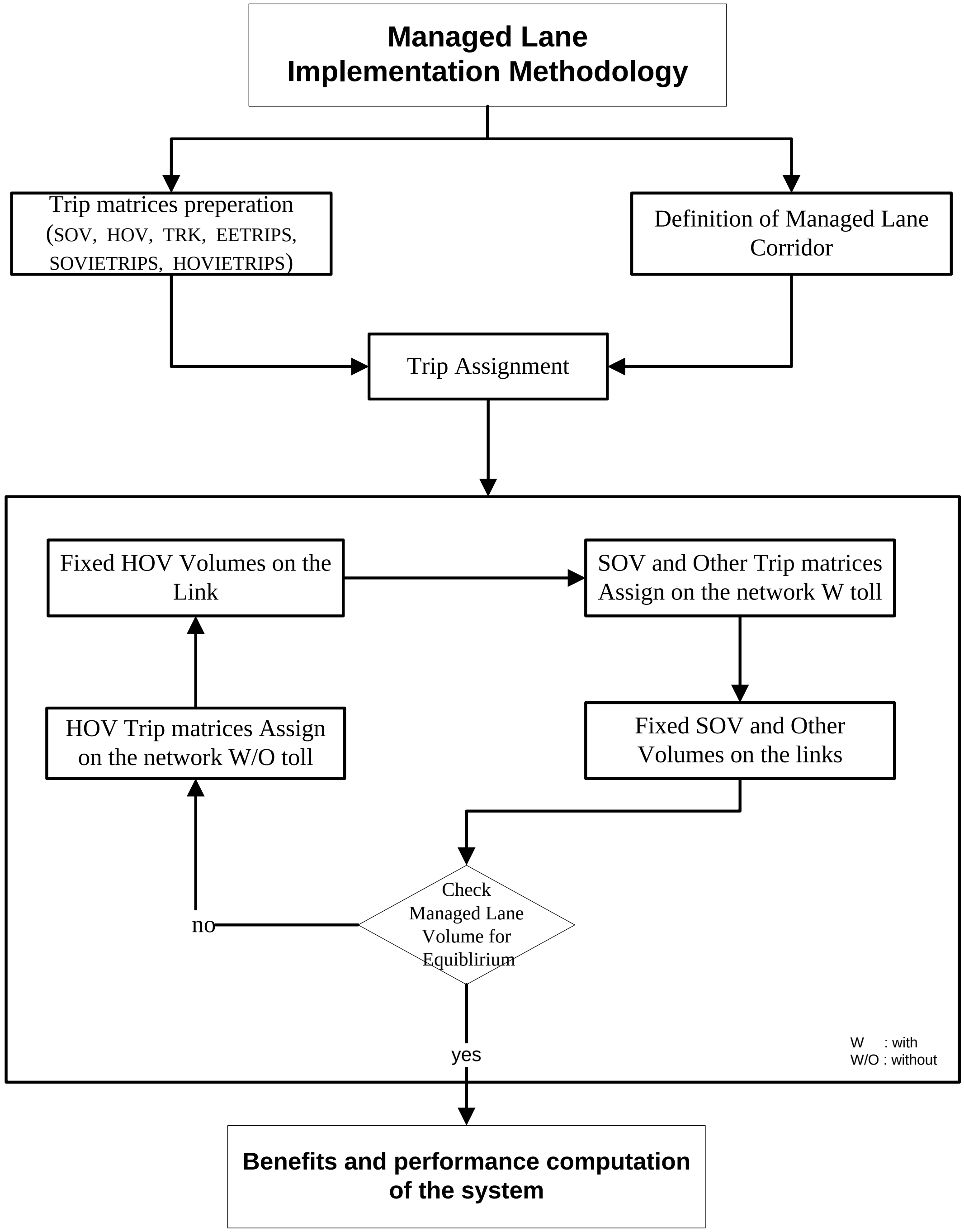


Figure 8-1 Evaluation Methodology of Managed Lanes

In the FSUTMS Olympus Model, there are a number of trip matrices that need to be assigned to the network including:

- Single occupancy vehicle matrix (SOV)
- Single occupancy vehicle external trip matrix (SOVIETRIPS)
- Truck matrix (TRK)
- High occupancy matrix (HOV)
- High occupancy external matrix (HOVIETRIPS)
- External-to external trip matrix (EETRIPS)

SOV, TRK and EETRIPS are considered to be Drive Alone matrices, and HOV, HOVIETRIPS are considered to be HOV matrices in the methodology.

One of the requirements listed in the previous section is that *The user shall be able to specify the threshold of number of persons per vehicle for the vehicle to use the managed lane for free.* Below is a discussion of how this is addressed in the methodology.

The HOV matrix is determined to reflect the estimated number of vehicles with occupancy above a certain thresholds (2 or 3) in the FSUTMS demand model. However, it may be necessary to specify that only a fraction of these vehicles are allowed to use the managed lanes. For example, in the Miami I-95 managed lane project, only preregistered HOV (three or more) that have permission to use the HOT lanes without paying the toll. Therefore, the HOV trip matrices are split into HOV-free and HOV-pay matrices, based on user input.

Another requirement is that *the Tool shall consider the willingness to pay of when calculating demands.* During the assignment process, the SOV matrices are split into those that are willing to pay and those that are not. This is done based Willingness to Pay (WtP) factor derived from a number of previous survey presented in

Table 8-5. The Default WtP table used in splitting the SOV matrix during the assignment is shown in Table 8-6 based on the results of

Table 8-5 normalized by the length of the section.

All other requirements presented in previous sections were also addressed in the developed tool. This includes the use of buses and trucks of the lanes. The user specifies toll values at discrete points in the network (where the electronic toll readers are actually located). The user can calculate the tolls at these points based on the covered lengths in miles and the toll rate per mile. The Tool produces results to check of the level of service on the managed lane(s) to the user such that the user can make changes to the specified toll at the discrete points to ensure acceptable levels of service on the managed lanes.

Table 8-6 Normalized WtP Lookup Table

Time saving (min/mile)							
≤0.45 **[95]		0.72 min*[96]		1.36 min*		>1.36 min**	
Toll	% of WtP	Toll	% of WtP	Toll	% of WtP	Toll	% of WtP
≤$2	10	$0.25	57.25	$0.5	52.87	≤$2	59
>$2	0	$1.25	39.31	$2.5	43.68	>$2	0
		$2.50	3.05	$5	3.07		
		$4.00	0.38	$8	0.38		
		>$4	0	>$8	0		

* Results of I-40 Survey
**Results of I-394 Survey

8.5 Implementation

The evaluation methodology presented in the previous section is implemented in the FSUTMS/Olympus model, using the script language of the Cube software. As with other types of ITS deployments, the user can select the managed lane evaluation from a pull down menu, as shown in Figure 8-2.

[95] Douma, F. and J. Zmud, "Pricing Comes to Minnesota: Baseline Attitudinal Evaluation of the I-394 HOT Lane Project," CD-ROM, Transportation Research Board, National Research Council, Washington, D.C.,2005.

[96] Benjamin, J., R. Sakano, B. McKinney, A. Khattak, D.A. Rodriguez and C. Gaskins, "An Analysis of Value Pricing in a Medium Sized City," CD-ROM, Transportation Research Board, National Research Council, Washington, D.C., 2006.

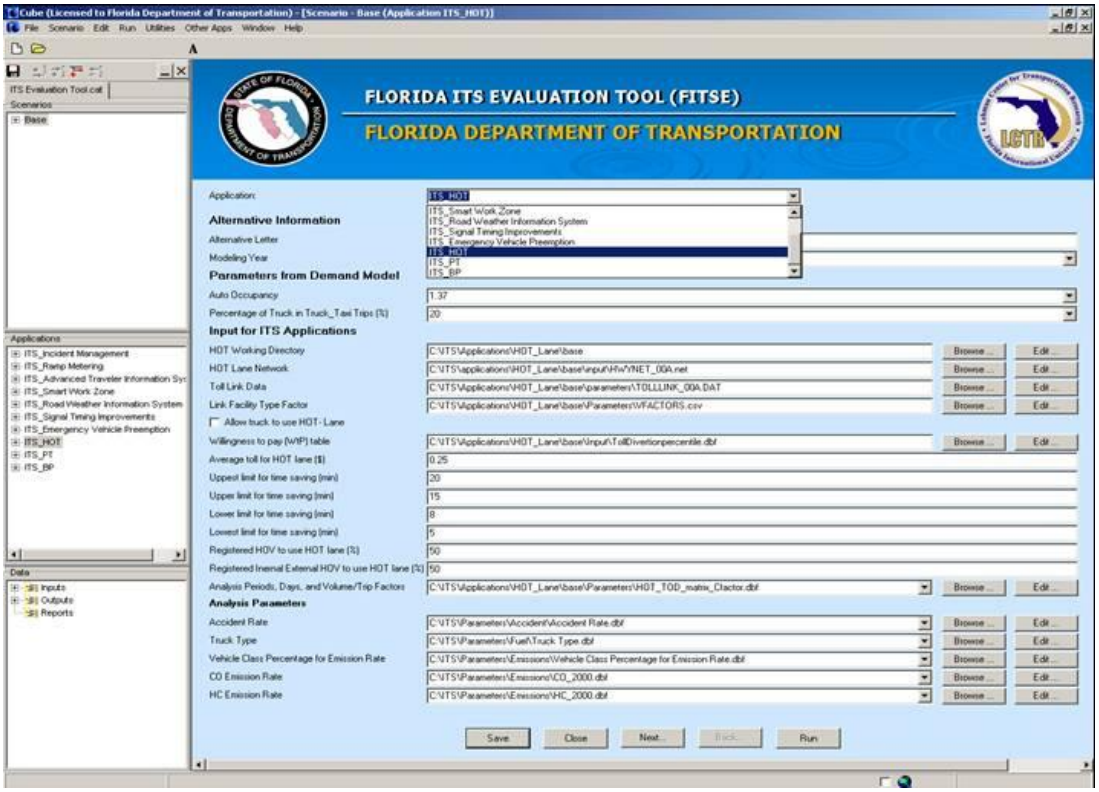


Figure 8-2 Selection of Managed Lane(s) as the ITS Deployment Type

8.5.1 The User Interface

As shown in Figure 8-3 and Figure 8-4 and as with other types of ITS deployments, the inputs are organized into different groups. Below is a list of some of these parameters that are specific to managed lane applications. These are discussed later in this chapter.

- Managed-lane toll factors in each period.
- Specification of managed lane network.
- Toll link data file.
- Link facility type factor file.
- Allow truck to use hot lane (it is a button command).
- Fraction of HOV matrix that can use the lane for free.
- Number of buses using the managed lane.
- Willingness to pay (WtP) table file (the default values are presented in Table 8-6).

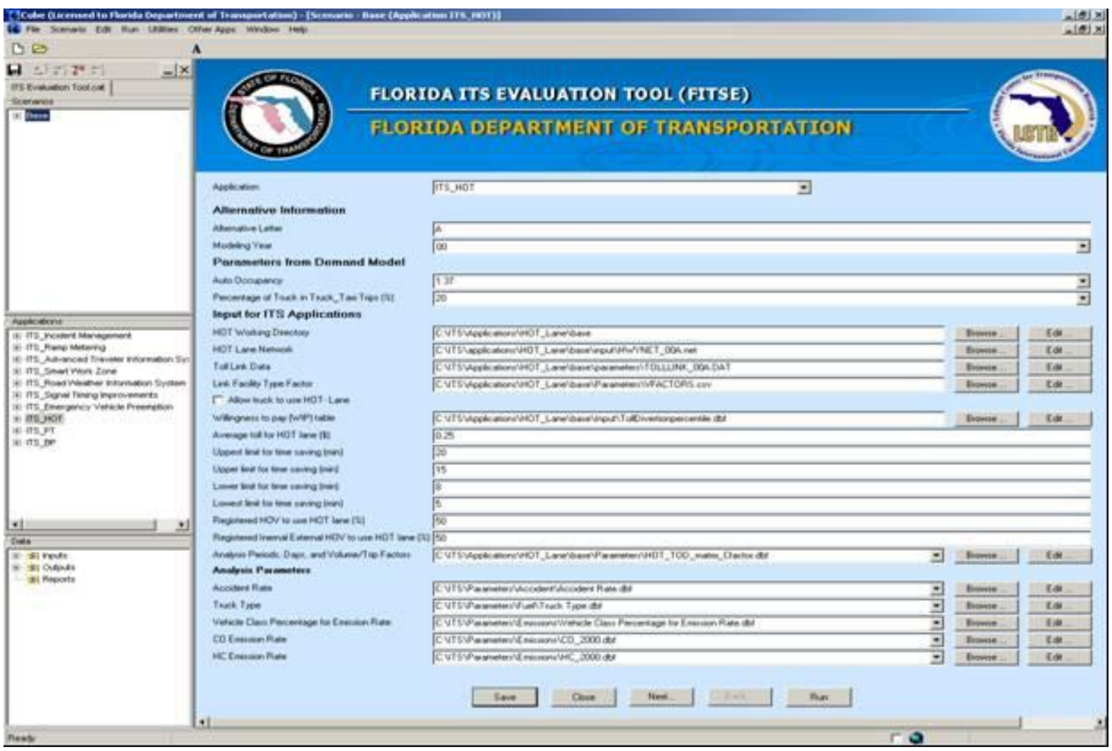


Figure 8-3 Interface to Input Parameters Related to Managed Lanes

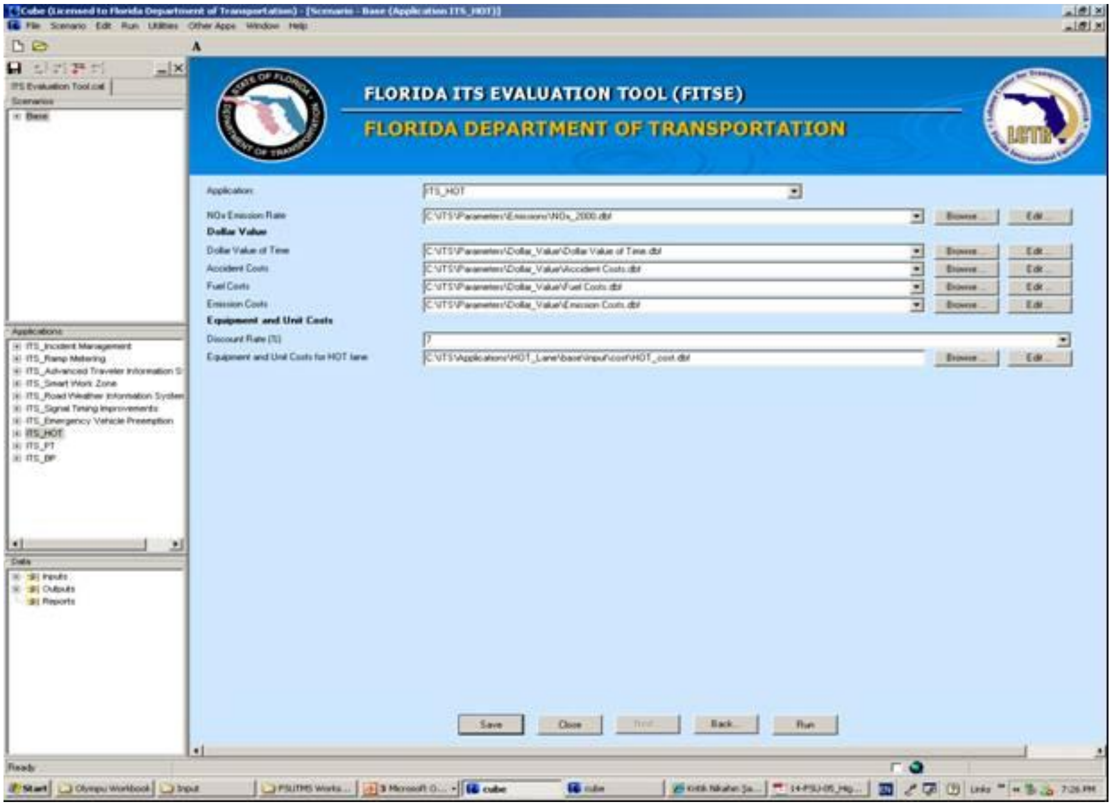


Figure 8-4 Additional Interface to Input Parameters Related to Managed Lanes

To specify the managed lane network configuration, new facility types were added to the FSUTM model. These new types specify the links to be either managed lanes or parallel general use lanes. These link types can be specified in the FTYPE attribute. Once the managed lanes are specified, the toll information associated with these lanes can be input. Figure 8-5 presents the original link attributes in the demand model.

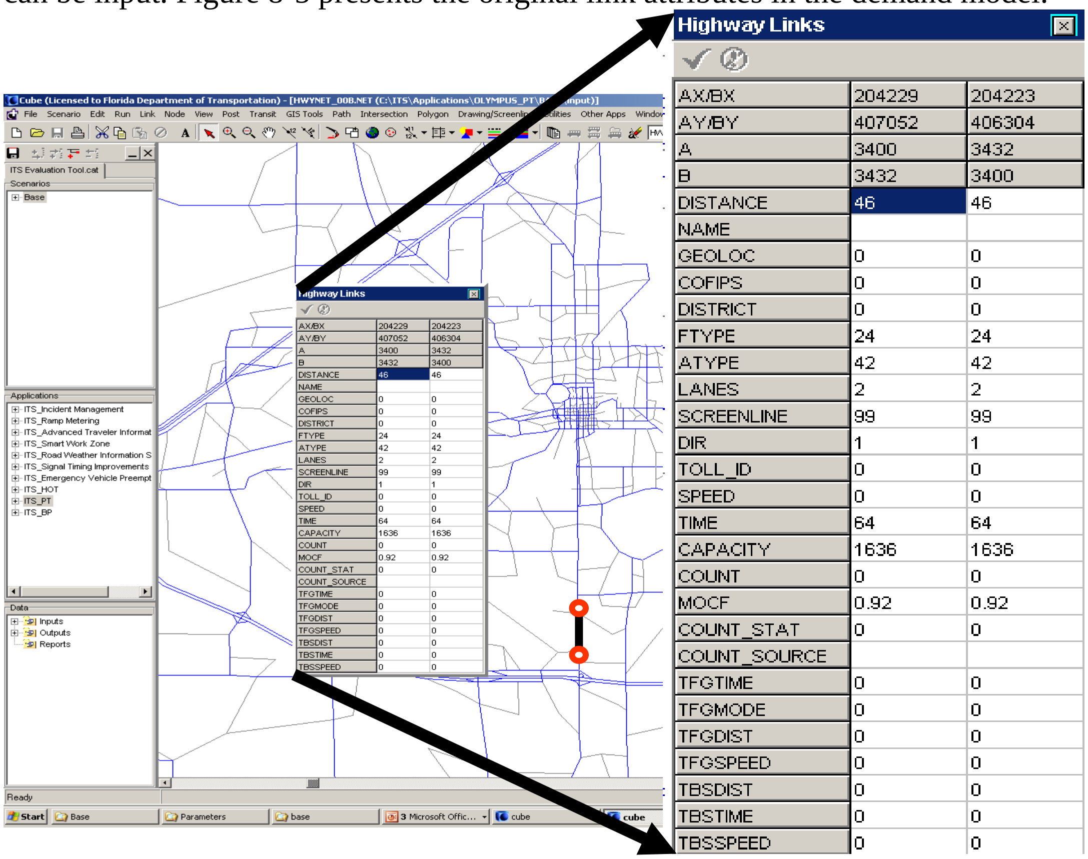


Figure 8-5 Original Link Attributes in the Demand Model

The user can convert existing links in the demand model to managed lane links or code new links for this purpose as shown in Figure 8-6.

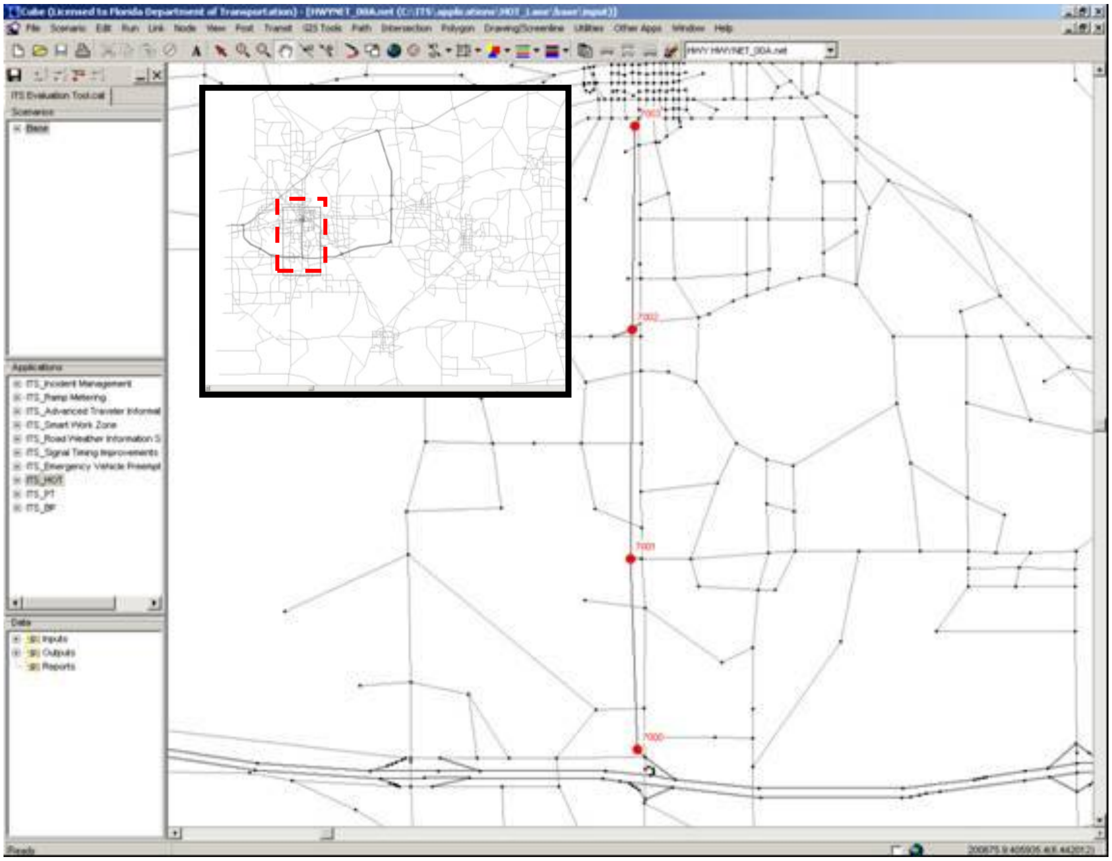


Figure 8-6 Coding New Managed Lane Links

The user can specify the links as managed lane links by adding the number 222 as the link FTYPE attribute, as shown in Figure 8-7. A new link "CORTYPE attribute was added to specify the corridor that is affected by the managed-lane operations. The corridor is defined as a managed lane facility and a general-use lane facility in the same direction, for which shifts in demands between the two facilities are possible depending on the estimated generalized costs of travel on the two facilities.

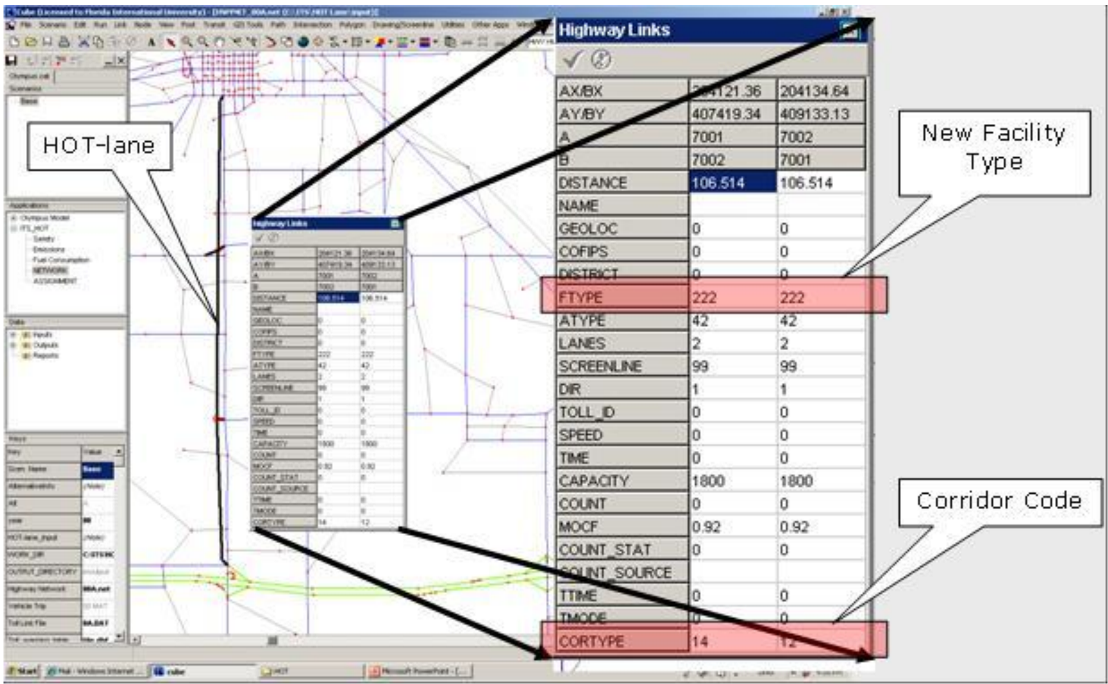


Figure 8-7 Definition of Managed Lanes in the Link Attribute Inputs

The CORTYPE attribute for corridors with no managed lanes should be coded as 0. The user needs to use a standard method to identify the corridor number for corridors with managed lanes to be coded in the CORTYPE attribute, as show in Figure 8-7. The number can be specified as follows (see Figure 8-8):

- The first digit shows whether the link is a general use or managed lane. Even numbers indicate managed lanes and odd numbers indicate GP lanes. Thus, 1B-2B, 3B-4B, 5B-6B, etc. are pairs of managed and GP lane groups.
- The second digit indicates the corridor direction as shown in Figure 8-8.

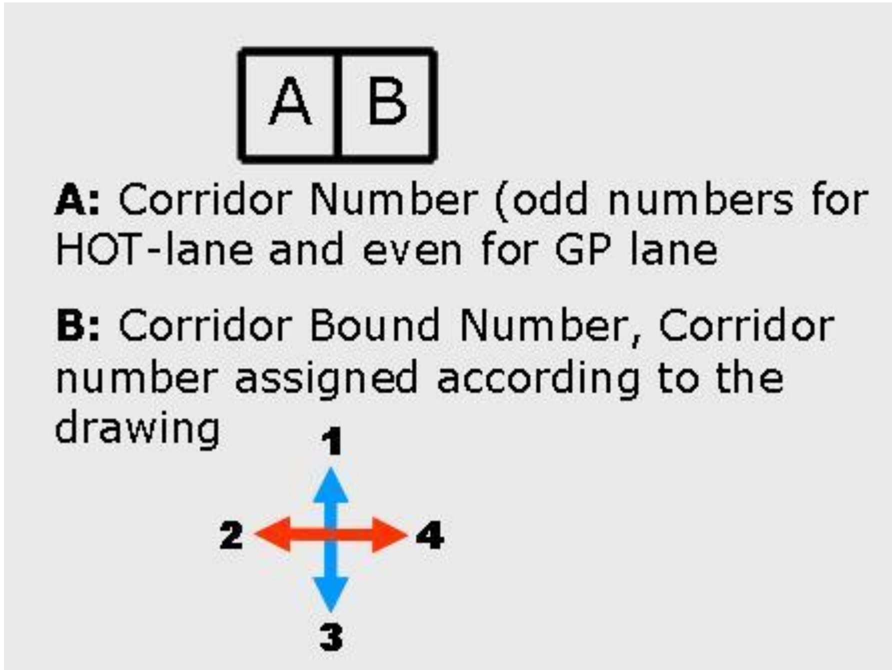


Figure 8-8 Specification of Corridor Number

An example of corridor coding is shown in Figure 8-9. In this figure, corridor code 13 indicates that link is part of Corridor 1 and its direction code is 3, indicating that it is an eastbound link of an East-West corridor. Corridor Code 24 for a link indicates that this link is part of Corridor 2 with direction code 4, indicating a northbound link on a north-south corridor.

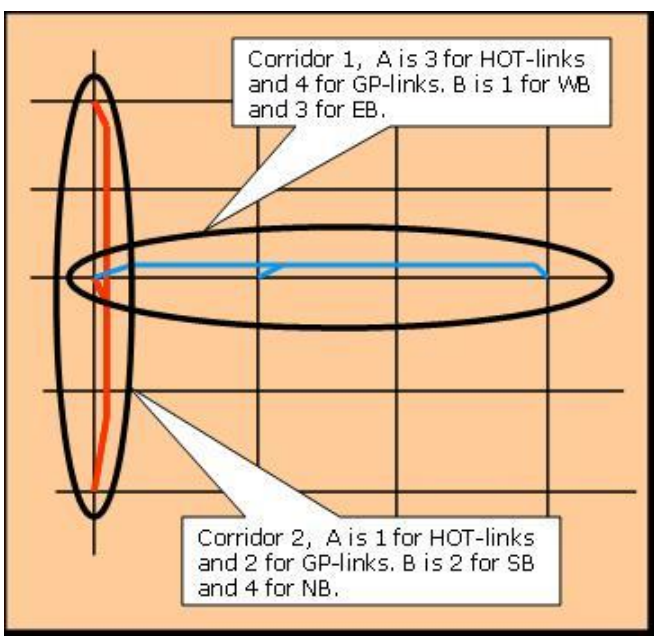


Figure 8-9 Corridor Numbering Examples

In the FSUTMS model, factors associated with facility types such as CONFAC, UROAD, and BPR curve are defined in the file (VFACTORS.CSV) that is shown in Figure 8-10. Information associated with the managed lane facility as a whole can be specified in this file. Toll information on the managed lane can be specified in the (TOLLLINK_00A.DAT) input file of the FSUTMS, as shown in Figure 8-11.

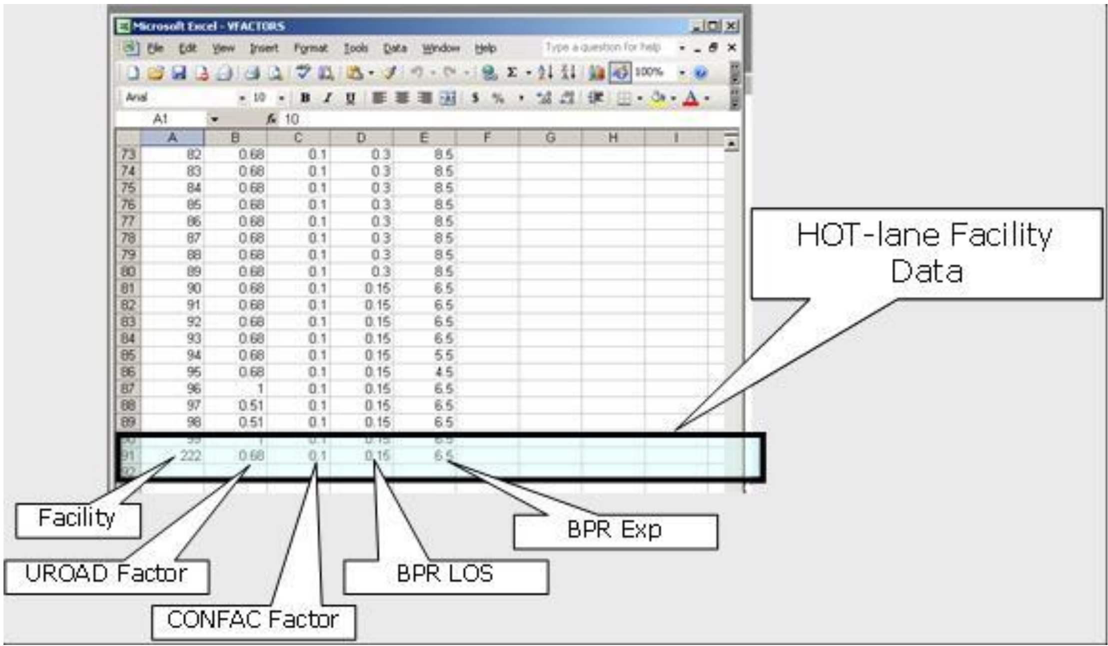


Figure 8-10 Specifying Factors Associated with Facility Types in FSUTMS

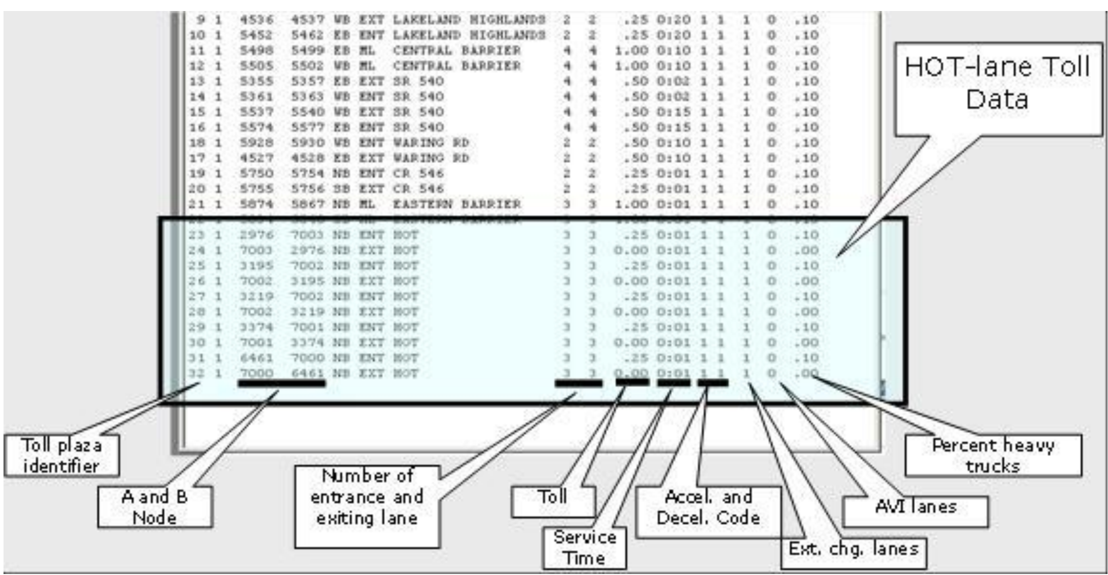
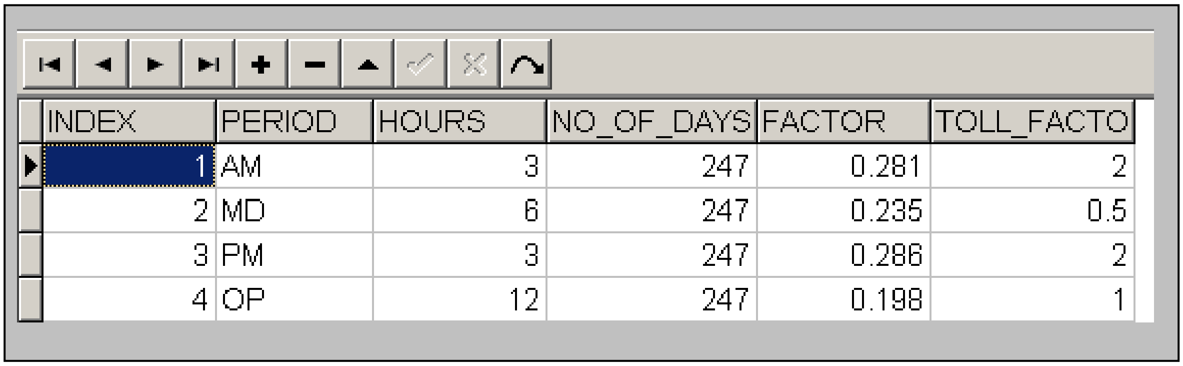


Figure 8-11 Specifying Toll Information

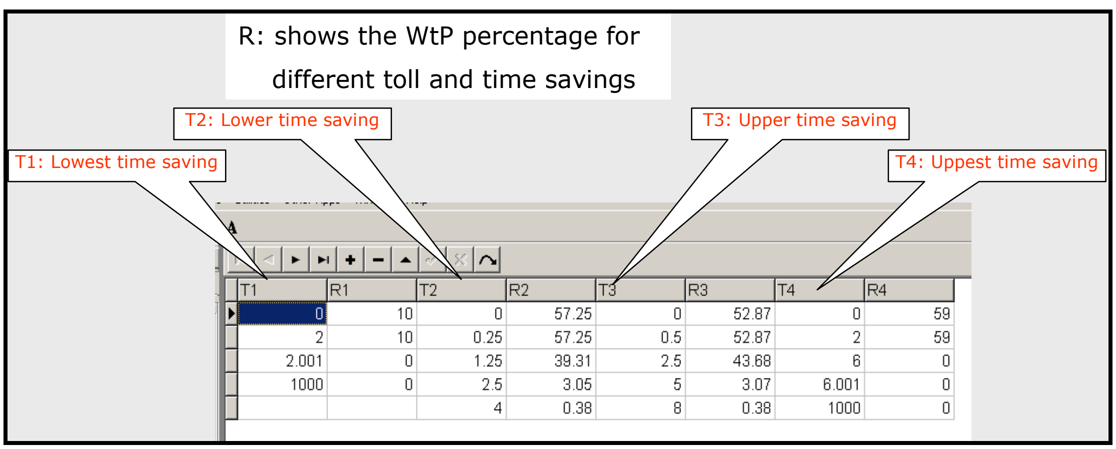
In the current implementation of managed lane, in the developed ITS Evaluation Toll, the toll values coded in the "TOLLLINK_00A.DAT" input file as specified above can be modified by time of day using a new factor referred to as (TOLL_FACTO), which is added to the TOD conversion table as shown in Figure 8-12**.** For example, if the toll for a managed lane is 0.25 dollar and the factor defined in the TOD table is 2 for a given period, then the toll used in calculating the generalized cost of the link is computed as 0.25 multiplied by 2, (0.50).



INDEX	PERIOD	HOURS	NO_OF_DAYS	FACTOR	TOLL_FACTO
1	AM	3	247	0.281	2
2	MD	6	247	0.235	0.5
3	PM	3	247	0.286	2
4	OP	12	247	0.198	1

Figure 8-12 Modifying Toll Information by TOD

The willingness to pay factors presented in Table 8-6 are saved also in a file and can be modified using the user interface as shown in Figure 8-13.



T1	R1	T2	R2	T3	R3	T4	R4
0	10	0	57.25	0	52.87	0	59
2	10	0.25	57.25	0.5	52.87	2	59
2.001	0	1.25	39.31	2.5	43.68	6	0
1000	0	2.5	3.05	5	3.07	6.001	0
		4	0.38	8	0.38	1000	0

Figure 8-13 Input of the Willingness-to-Pay Factors

8.5.2 Modeling Structure

For managed lane evaluation implementation, the modeling structure consists of Network setting, TOD Assignment, and Benefit and Cost modules, as shown in Figure 8-14. For detailed implementation procedures, the user is referred to the catalog in Cube software.

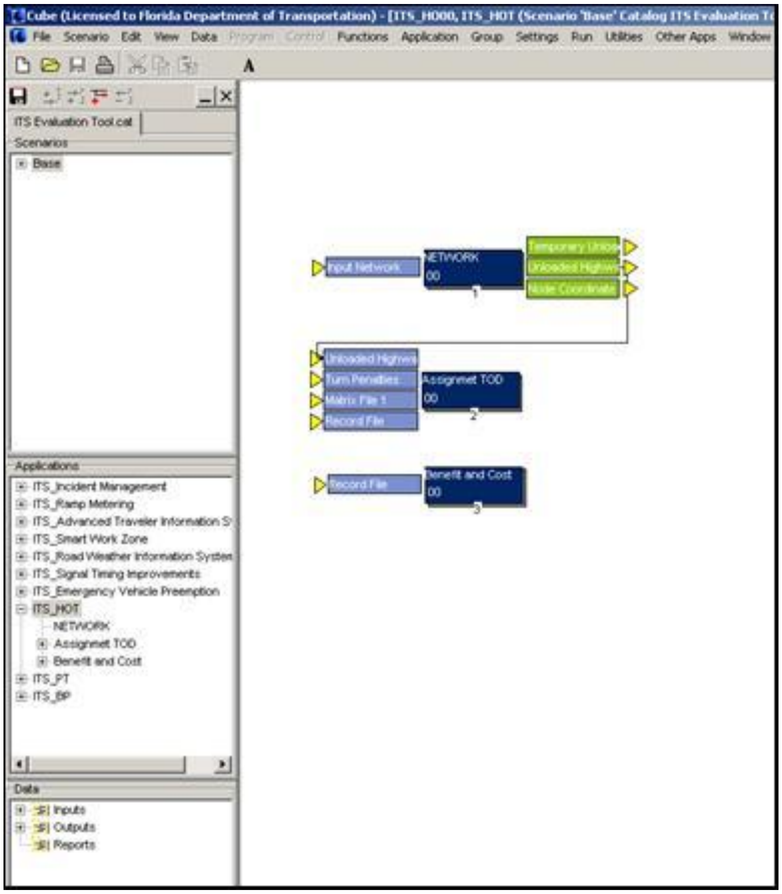
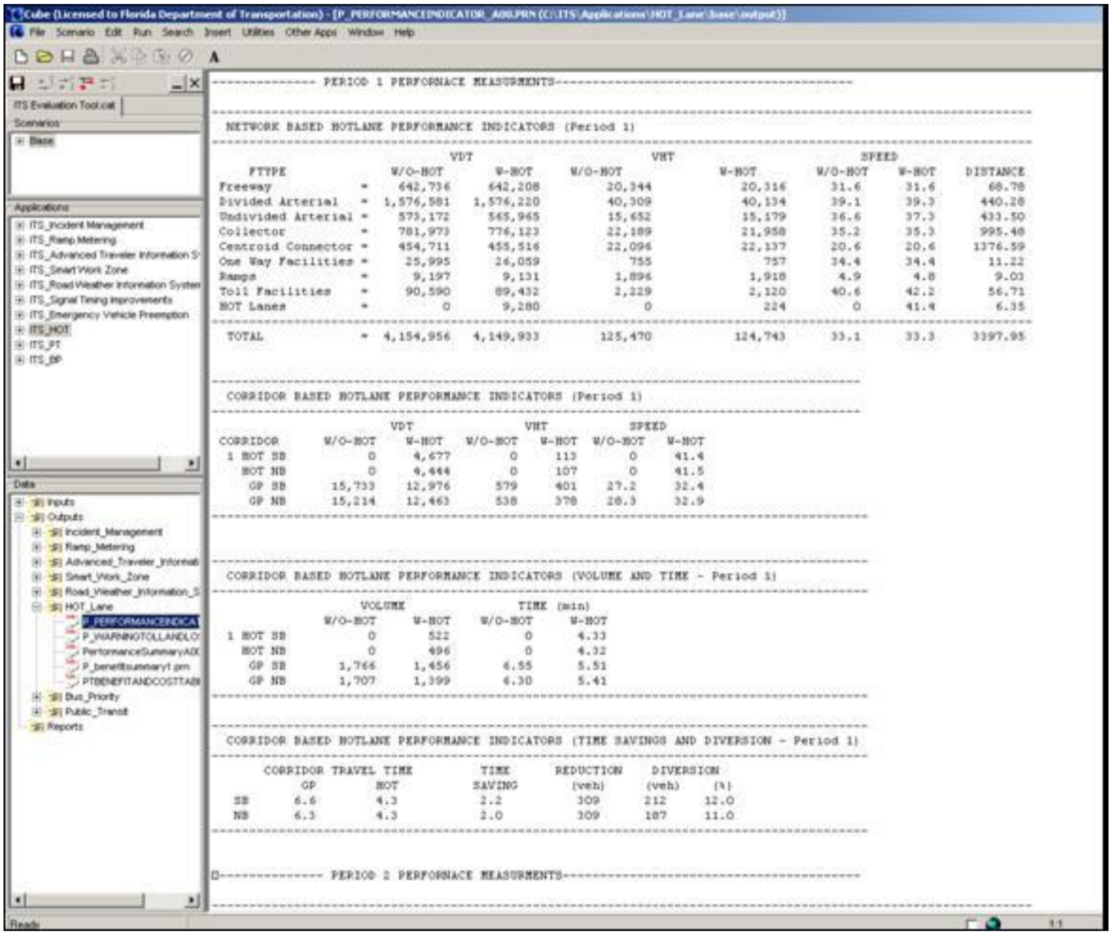


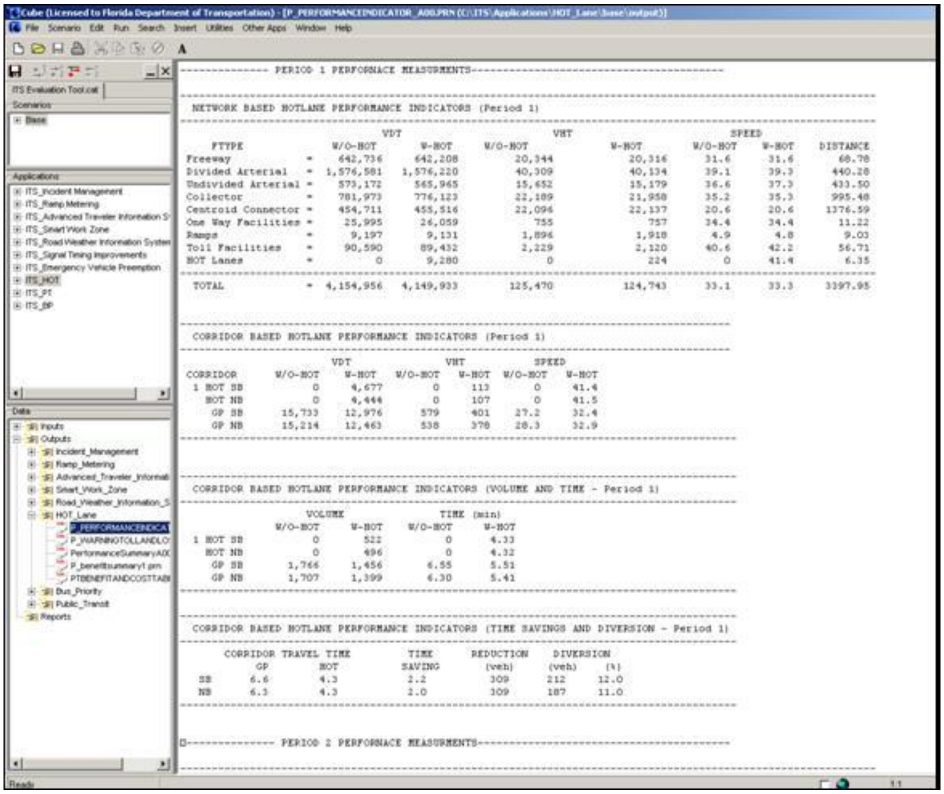
Figure 8-14 Modeling Structure for Evaluating Managed Lanes

8.5.3 Output Files

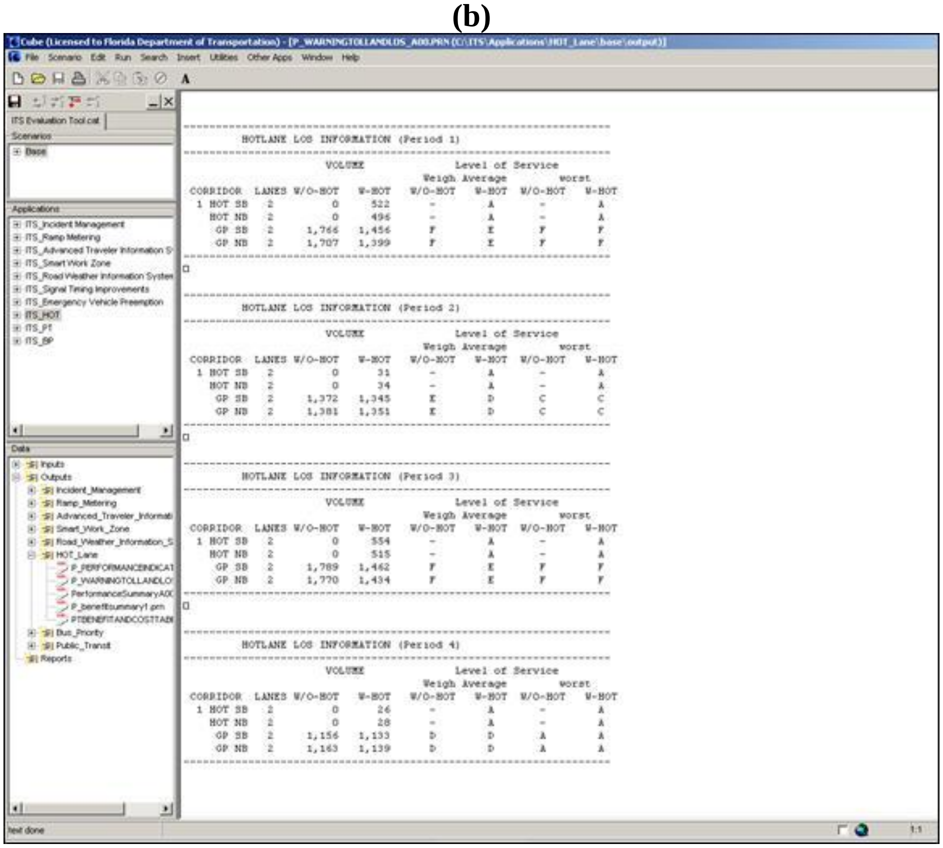
Three standard files are generated to report the results of managed lane the performance summary, 2) the benefits summary, and 3) the benefits and summary files. These three files (examples are shown in Figure 8-15 to Figure 8-17) are organized under the output category in the data window.


Cube (Licensed to Florida Department of Transportation) - [P_PERFORMANCEINDICATOR_A00.PRN (C:\ITS\Applications\HOT_Lane\base\output)]
File Scenario Edit Run Search Insert Utilities Other Apps Window Help
PERIOD 1 PERFORMACE MEASURMENTS
NETWORK BASED HOTLANE PERFORMANCE INDICATORS (Period 1)
VDT VHT SPEED
FTYPE W/O-HOT W-HOT W/O-HOT W-HOT W/O-HOT W-HOT DISTANCE
Freeway = 642,736 642,208 20,344 20,316 31.6 31.6 68.78
Divided Arterial = 1,576,581 1,576,220 40,309 40,134 39.1 39.3 440.28
Undivided Arterial = 573,172 565,965 15,652 15,179 36.6 37.3 433.50
Collector = 781,973 776,123 22,189 21,958 35.2 35.3 995.48
Centroid Connector = 454,711 455,516 22,096 22,137 20.6 20.6 1376.59
One Way Facilities = 25,995 26,059 755 757 34.4 34.4 11.22
Ramps = 9,197 9,131 1,896 1,918 4.9 4.8 9.03
Toll Facilities = 90,590 89,432 2,229 2,120 40.6 42.2 56.71
HOT Lanes = 0 9,280 0 224 0 41.4 6.35
TOTAL = 4,154,956 4,149,933 125,470 124,743 33.1 33.3 3397.95
CORRIDOR BASED HOTLANE PERFORMANCE INDICATORS (Period 1)
VDT VHT SPEED
CORRIDOR W/O-HOT W-HOT W/O-HOT W-HOT W/O-HOT W-HOT
1 HOT SB 0 4,677 0 113 0 41.4
HOT NB 0 4,444 0 107 0 41.5
GP SB 15,733 12,976 579 401 27.2 32.4
GP NB 15,214 12,463 538 378 28.3 32.9
CORRIDOR BASED HOTLANE PERFORMANCE INDICATORS (VOLUME AND TIME - Period 1)
VOLUME TIME (min)
W/O-HOT W-HOT W/O-HOT W-HOT
1 HOT SB 0 522 0 4.33
HOT NB 0 496 0 4.32
GP SB 1,766 1,456 6.55 5.51
GP NB 1,707 1,399 6.30 5.41
CORRIDOR BASED HOTLANE PERFORMANCE INDICATORS (TIME SAVINGS AND DIVERSION - Period 1)
CORRIDOR TRAVEL TIME TIME REDUCTION DIVERSION
GP HOT SAVING (veh) (veh) (%)
SB 6.6 4.3 2.2 309 212 12.0
NB 6.3 4.3 2.0 309 187 11.0
PERIOD 2 PERFORMACE MEASURMENTS

(a)



(b)



(c)

Figure 8-15 Performance Summary Output for Managed Lanes

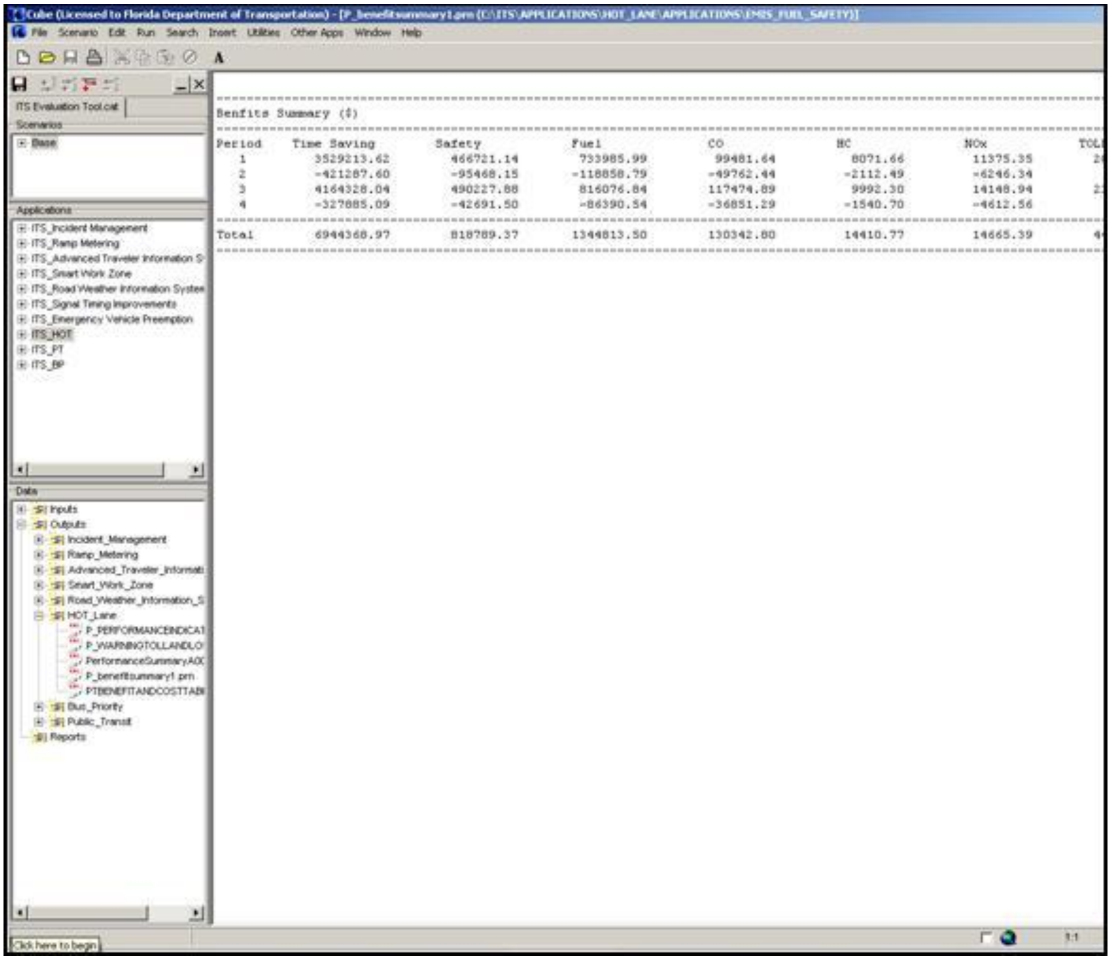


Figure 8-16 Benefit Summary Output for Managed Lanes

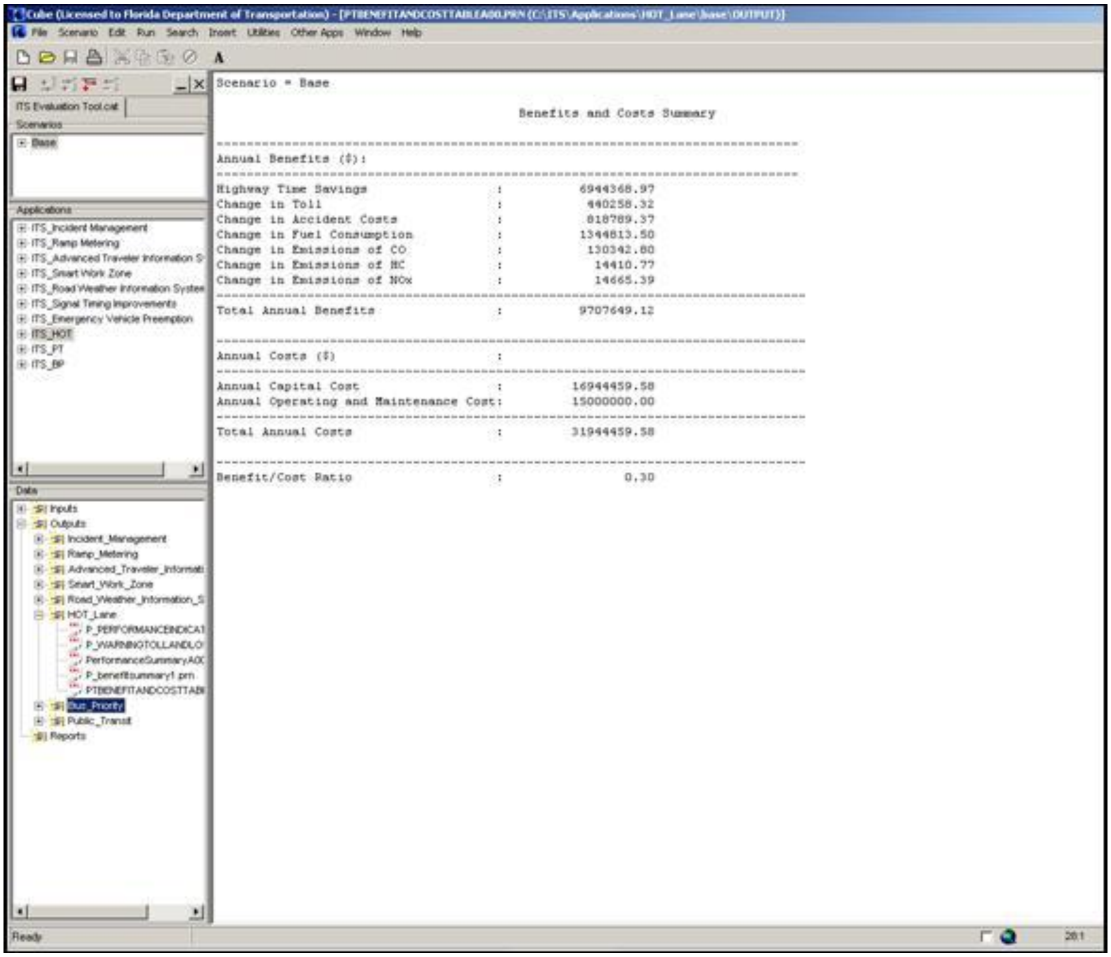


Figure 8-17 Benefit and Cost Summary Output for Managed Lanes

9 Smart Work Zones

Smart work zones (SWZ) are automated systems that provide real-time information on work zone traffic conditions. In recent years, transportation agencies across the nation have deployed portable ITS technologies to monitor traffic and manage mobility and safety during construction and maintenance of highways. Portable ITS systems provide a solution for deployment, maintenance, and operation during these conditions. Most of these systems take the form of mobile traffic monitoring and management through the use of portable sensors to collect traffic data, along with integrated portable changeable message signs (PCMS) to display speed and/or delay information in real-time. Agencies also often integrate a website into the overall system to provide motorists with pre-trip information to allow for better trip planning. A few agencies have also used portable ITS to help manage merging behavior approaching work zone lane closures. Other types of SWZ include speed advisory systems, dynamic speed limits, and automated speed enforcement. This chapter addresses the modules that evaluate benefits and costs using various types of SWZ systems.

9.1 Previous Approaches to Evaluation

The primary objective of the Smart Work Zone system is to improve safety and mobility for motorists by providing them with real-time information regarding traffic conditions and alternate route options. Information commonly provided at smart work zones include:

- Speed advisory messages, where approaching traffic is alerted to slower speeds in the work zone.

- Travel time or delay messages, where approaching traffic is informed of the estimated travel time or delay to travel through the work zone.

- Diversion guidance, where messages on possible alternate routes are displayed.

- Merging support, where advisory signs are provided regarding when to merge from a closed lane.

IDAS does not have modules for evaluating smart work zones. As described later in this section, ITSOAM estimates the safety benefits of providing speed advisory messages to motorists, but it does not consider any mobility benefits attributed to the smart work zones. This section also provides a review of previous studies that are related to the evaluation approach proposed in this study to evaluate smart work zones.

9.1.1 Mobility Benefits

This section describes the benefits of information provision to motorists and addresses the benefits of dynamic lane merge information systems.

Benefits of Information Provision to Motorists

Based on an extensive review of literature, Fontaine[97] found that:

- Between 4 and 20 percent of mainline traffic diverted in response to travel time or delay information during congested conditions. Minimal diversion was observed in response to speed advisory information. Diversion percentages were usually greater when specific alternate routes were specified or when the alternate routes could be obviously seen from the mainline highway.
- Drivers who traveled the corridor with the SWZ frequently were more likely to change their paths in response to delay or travel time information than those who drove the corridor infrequently.
- Speed advisory systems appeared to be effective at getting drivers to reduce speeds approaching work zones, but the benefits appeared to be most pronounced during congested operation. Researchers found that speed advisory messages were effective only when density exceeded 40 vehicles per mile.

The authors used simulation analysis to evaluate the impacts of SWZ when implemented in a simple network with one alternative route to a two–lane directional freeway with a lane closure, as shown in Figure 9-1.

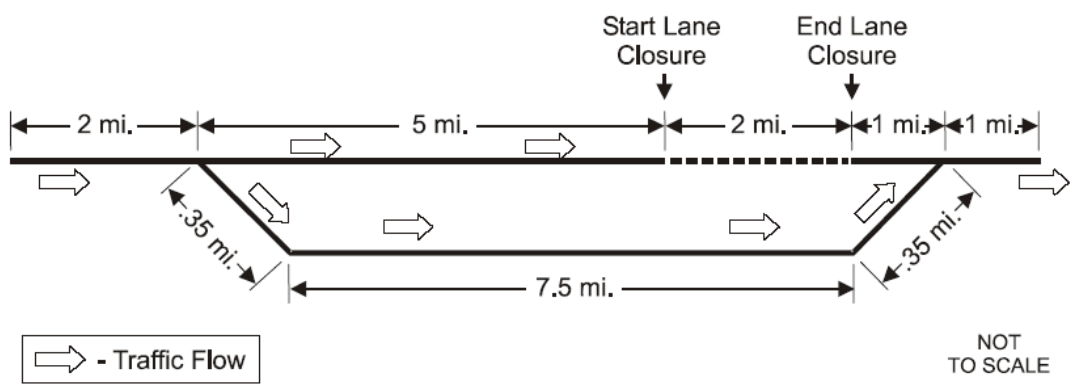


Figure 9-1 Network Used in Fontaine Study

[97] Fontaine, M.D., "Guidelines for the Application of Portable Work Zone Intelligent Transportation Systems," In *Transportation Research Record 1824,* Transportation Research Board, National Research Council, Washington, D.C., 2003.

Three different diversion scenarios were tested: 1) a no diversion case, 2) a 5 percent diversion case, and 3) a 15 percent diversion case. These levels were derived from the observed diversion percentages found in prior tests of SWZs. These are intended to represent situations where 1) no SWZ is in place, 2) where travel time information is provided but no specific diversion information is presented and the diversion route is not apparent, and 3) a best case scenario where a diversion route is obvious or specific route information is provided. A series of microscopic traffic simulations were developed using VISSIM to identify the benefit/cost ratio with different days of operation of the system. Table 9-1 illustrates the results from the analysis.

Benefits of Dynamic Lane Merge

The methodology presented above is for smart work zone applications that provide real-time information that allow drivers to divert. Another type of smart work zone applications, the dynamic lane merge (DLM) is also expected to provide significant mobility benefits. The basic concept of the DLM control strategy is that it can respond to real-time traffic conditions detected by a set of sensors (e.g., a microwave or video image sensor) in the upstream segment of the lane-closed work zone, and then regulate the merging actions of drivers (e.g., merging times and locations) based on the pre-determined control thresholds.

The University of Nebraska examined PennDOT's late merge strategy in a 1999 study.[98] The field tests of a 2-to-1 lane reduction scenario showed that the use of the late merge resulted in 75 percent fewer forced merges and a capacity (throughput) increase of 1,470 passenger car per hour per lane (pcphpl), versus 1,340 pcphpl for the standard lane merge. Benefits were found to be most evident during periods of heavy congestion. Kang et al.[99] evaluated DLM and found an increase in work zone throughput that ranged between 6.9 percent (1432 pcphpl vs. 1340 pcphpl) to 17.8 percent (1578 pcphpl vs. 1340 pcphpl).

[98] McCoy, P.T., G. Pesti and P.S. Byrd, "Alternative Information to Alleviate Work Zone- Related Delays," Report SPR-PL-1(35)P513, University of Nebraska, Lincoln, 1999.

[99] Kang, K.P., G.L. Chang and J. Paracha, "Dynamic Late Merge Control at Highway Work Zones: Evaluation Observations, and Suggestions," TRB 2006 Annual Meeting Proceedings, Washington, D.C., January 2004.

Table 9-1 B/C Ratios Durations Obtained in Fontaine Study

Peak Hour Volume (vph)	Diversion %	Alternate Route Speed (mph)	$150,000 Initial Cost		$300,000 Initial Cost	
			30 Day B/C	150 Day B/C	30 Day B/C	150 Day B/C
1,500	5	25	0.5	2.5	0.2	1.2
	5	35	0.8	4.1	0.4	2.1
	15	25	No Saving			
	15	35	0.6	3.0	0.3	1.5
1,600	5	25	2.2	11.2	1.1	5.6
	5	35	2.5	12.7	1.3	6.3
	15	25	2.4	11.9	1.2	6.0
	15	35	3.7	18.3	1.8	9.1
1,700	5	25	4.5	22.7	2.3	11.4
	5	35	5.0	25.2	2.5	12.6
	15	25	7.5	37.4	3.7	18.7
	15	35	9.2	46.2	4.6	23.1
1,800	5	25	6.9	34.3	3.4	17.1
	5	35	7.6	38.1	3.8	19.1
	15	25	13.2	66.0	6.6	33.0
	15	35	15.8	79.1	7.9	39.5

9.2 Safety Benefits

Previous studies have indicated that work zones significantly increase crash rates in the highway sections where the work is performed. Below is a summary of previous studies that addressed the safety of work zones and the impacts of advanced technologies on this safety. The results from a number of studies indicate that the introduction of work zones lead to an increase in crash rates, however, these studies vary extensively in their estimations for the increase in crash rate. The ITSOAM user guide review of previous studies indicated an increase in crash rates ranging from 7 percent to 119 percent for segments with work zones compared to the same segments without work zones. This wide range indicates that a substantial uncertainty regarding the increase in crash rates in work zones. Huebschman et al.[100] reported that accident rates increase about 30 percent on interstates with work zones. The increase in the crash rate is expected to be dependent on traffic and geometric conditions, traffic control devices, and other aspects of the work zone environment. Venugopal and Tarko[101] attributed the increase in crash rate at work zones to the general disruption of traffic due to lane closures, improper lane merging maneuvers, and the inappropriate use of traffic control devices.

An Arkansas smart work zone evaluation study examined a system that detects the queue lengths at work zones and subsequently reports delay times and speed advisories to travelers via a roadside changeable message signs. In addition, a HAR system at the site provides the public with general work zone information and informs travelers of expected delays. The effectiveness of the system was determined by comparing the evaluated site (Lonoke County site) with two comparable construction sites not using the system (Brinkley-Goodwin and Goodwin-East). The analysis found that the fatal crash rate in Lonoke County was lower than both of the comparison sites. These results are summarized in Table 9-2.[102]

[100] Huebschman, C., C. Garcia, D. Bullock and D. Abraham, "Compliance with Reduced Speed Limits in Work Zones," Transportation Research Board 2004 Annual Meeting CD-ROM. Washington, DC, 2004.

[101] Venugopal, S. and A. Tarko, "Indiana Lane Merge Control System - Warrants for Use," Joint Highway Transportation Program Final Report, FHWA/IN/JTRP-2000-19, Washington DC 2000.

[102] "Intelligent Transportation Systems in Work Zones -- Cross-Cutting Study," U.S. Department of Transportation, Federal Highway Administration, November 2002.

Table 9-2 Safety Improvements Due to Smart Work Zone Deployment in Arkansas

Description	Period of Crash Data used in the Analysis	Fatal Crash Rate Per 100 Million Vehicle Miles Traveled	Rear-End Crash Rate Per 100 Million Vehicle Miles Traveled
Lonoke County Site (with AWIS)	*July 2000 thru June 2001	2.2	33.7
Brinkley – Goodwin (without AWIS)	*July 2001 thru December 2001	3.4	43.2
Goodwin – East (without AWIS)	*July 2000 thru Sept. 2001	3.2	29.5

*The period of the crash data for these projects corresponds with the time the work zone was active. Crash data was only available through December 2001.

Another study[103] reviewed the international experiences on the effects of Automated Speed Enforcement (ASE) on safety. This study under review was done in the Netherlands; it evaluated the effects of ASE when combined with variable message sign warnings. This study found that average speeds were reduced by 5 km/h (3 mph) and that the 85th percentile speeds were reduced by 8 km/h (5 mph). The percent of vehicles speeding declined by 27 percent after the system was installed. In Norway, the number of injury accidents on the portions of road with the ASE systems declined by an average of 20 percent, and the total number of accidents on these sections declined between 5 and 26 percent.

Garber and Gadiraju[104] developed models that predict the influence of speed variance on accident rates (AACRT) as a function of speed variance (SPVA) as follows:

Interstate: $AACRT = 43.2 + 0.00347(SPVA)^2$

Arterial: $AACRT = 168 + 0.00273(SPVA)^2$

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[103] Fontaine, M. and S. Schrock, "Feasibility of Real-Time Remote Speed Enforcement in Work Zones," Paper presented at the 81st Transportation Research Board Annual Meeting, Washington, DC. 13-17 January 2002.

[104] Garber, N.J. and R. Gadiraju, "Factors Affecting Speed Variance and Its Influence on Accidents," AAA Foundation for Traffic Safety, Falls Church, VA. July 1988.

Since speed advisory and/or enforcement are expected to reduce speed variance, the above equations are useful to estimate the safety impacts of smart work zones. Benakohal and Shu[105] found that the speed dispersion dropped by 5 to 7 percent when passive VMS was deployed (due to a reduction of vehicles driving over the speed limit). Dynamic VMS coupled with a radar unit have been reported to be more effective in terms of motorist response, than passive systems. Garber and Patel[106] found that speed dispersion dropped by 5 to 35 percent on Virginia interstates. The ITSAOM user guide recommended based on review of previous studies, to use values of the reduction in SPVA due to smart work zone speed advisories, between the values of 5 percent and 25 percent. ITSAOM uses the Garber and Gadiraju[107] equations listed above to predict the safety effects of smart work zone based on the reduction of SPVA.

King et al.[108] evaluated advanced dynamic speed advisory systems; they recommend that the safe speed at work zones should be based on existing measured conditions. Such systems have the potential to warn drivers of congestion near work zones and streamline traffic approaching the work zone. The evaluation showed that vehicle speeds closest to the work zone were approximately 7 mph less when the system was operating dynamically as compared to when the system was not deployed. Statistical testing showed that vehicles usually decreased their speed when congestion and VMS were in place.

Sullivan et al.[109] evaluated a prototype queue-warning system that alerts drivers approaching slow moving traffic ahead. The results based on a driving simulator study showed that the queue warning systems increased drivers' minimum time to collision by about 1 second, and reduced peak deceleration by about 3.3 ft/sec^2. Both measures suggest that drivers were better prepared to stop than when the roadway was treated with static warning signs.

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[105] Benekohal, R.F. and J. Shu, "Speed Reduction Effects of Changeable Message Signs in a Construction Zone: A Report of the Findings of Investigation of Speed Control Methods in Work Zones," Illinois Department of Transportation, Urbana, IL, Report FHWA-IL/UI-239, 1992.

[106] Garber, N.J. and M.D. Fontaine, "Controlling Vehicle Speeds in Work Zones: Effectiveness of Changeable Message Signs with Radar," Mid-Atlantic Universities Transportation Center, University of Virginia, Charlottesville, VA, 1996.

[107] Garber, N.J. and R. Gadiraju, "Factors Affecting Speed Variance and Its Influence on Accidents, AAA Foundation for Traffic Safety," Falls Church, VA. July 1988.

[108] King, T., C. Sun and M.R. Virkler, "Evaluation of a Freeway Work Zone Advance Speed Advisory System Using Multiple Measures," TRB 2004 Annual Meeting Proceeding, Washington, D.C., January 2004.

[109] Sullivan, J.M., C.B. Winkler, M. Hagan and P. Huang, "Development of a Smart Drum to Warn Drivers about Speed Differentials in Work Zones," TRB 2006 Annual Meeting Proceedings, Washington, D.C., 2006.

9.3 Assessment

Based on the results presented above, it appears that the different types of smart work zones vary in their expected impacts on safety and mobility. These systems include:

- Speed advisory with a VMS feedback based on detector measurements.
- Speed advisory or dynamic speed limit based on an algorithm that calculates safe speed based on traffic condition measurements.
- Queue warning systems.
- Systems that provide delay information.
- Systems that provide alternative route information.
- Dynamic merge systems.

The user should be able to code the type of the smart work zone in the evaluation tool and this type should be considered when calculating the benefits and costs.

9.4 Cost

Smart Work Zones are not considered in IDAS. Thus, no cost values are available for them from the IDAS database or the Florida specific ITS cost database. A study done by Fontaine (see Section 9.1 above) reported that the cost of smart work zones recently deployed in North Carolina varies between $150,000 and $300,000 per location. Recently, the FDOT District 4 estimated the cost for its new installation of a smart work zone that provides speed advisory at $115,000. It is recommended that the cost of a smart work zone should be set between $100,000 and $250,000, depending on the SWZ capabilities.

9.5 Requirement Analysis

Below are the requirements for the evaluation of SWZ deployments:

- The user shall be able to select the (links) on which a smart work zone(s) will be implemented.

- The user shall be able to specify the period of time associated with the operation of the equipment at each zone.

- The user shall be able to specify that the percentage of the equipment associated with a given deployment. The user needs to externally calculate these percentages based pm the potential for reuse of the same equipment at multiple locations for different times of the year.

Analysis: This is done to reflect the fact that the SWZ are generally mobile equipment and can be moved from one location to another. Thus, its cost and benefits should be calculated for the period for which it is active on a given link. For other periods, it is assumed that the work zone will be used in other locations.

- For each SWZ, the user shall be able to select the type of SWZ including the provision of congestion information, alternate route information, dynamic merge information, speed advisory, and queue warning systems.

- The Tool shall be able to model the drop in capacity and the reduction in delays due to work zones.

- The Tool shall be able to model the drop in capacity and increase in accidents due to work zones.

- The Tool shall calculate the mobility impacts due to providing congestion and/or route information at SWZ:

    - The Tool shall be able to calculate the mobility benefits due to diversion as a result of congestion and/or route information provided to motorists at the SWZ.

    - The Tool shall calculate the impacts of diversion on alternative routes.

- The Tool shall be able to evaluate the provision of dynamic lane merge information at SWZ on mobility and safety.

- The Tool shall evaluate the effect of the provision of speed advisory and queue warning on safety.

- The Tool shall calculate the impacts of SWZ on fuel consumption and emission at work zone.

Analysis: Technical Memorandum Number 1 recommended that the PDO, injury, and fatality crash rates can be reduced by 5 percent, 10 percent, and 15 percent, respectively for freeways and 2 percent, 4 percent, and 4 percent, respectively for arterials. The crash rate on a work zone segment will be assumed 30 percent higher than the crash rate on the same segment without smart work zone.

9.6 Methodology

As discussed earlier in this chapter, the primary objectives of a smart work zone (SWZ) is to improve the safety and mobility for motorists by providing them with real-time information regarding work zone traffic conditions and alternative route options.

Section 9.5 specifies that *the user shall be able to select the (links) on which a smart work zone(s) will be implemented, the period of time associated with the operation of the equipment at each zone, and possibility of sharing equipment between zones considering that the equipment is mobile and can be moved as needed.*

The requirements of Section 9.5 also specifies that *for each SWZ, the user shall be able to select the information provided by SWZ equipment.*

Various types of information can be provided at smart work zone. The tool will be able to model the benefits type of SWZ including the provision of congestion information, alternate route information, dynamic merge information, speed advisory, and queue warning systems. Since the major impacts vary with the type of smart work zone, different evaluation methodologies will be applied to different types of smart work zone.

Section 9.5 also specifies that *the Tool shall be able to model the drop in capacity on the effected links and the resulting delay due to SWZ.*

In this study, the method proposed in HCM2000 is employed to calculate freeway work zone capacity, which is expressed as:

$$C_a = (1600 + I - R) \times f_{HV} \times N \tag{9-1}$$

where C_a is adjusted mainline capacity at SWZ in vehicles per hour. 1600 pcphpl is the base value for work zone capacity. I represents the adjustment factor for work zone type, work intensity, and location of the work zone activities, ranging from -160 to +160 pcphpl. R is the adjustment factor due to the presence of on-ramps within the tape area or within 500 ft of work zone downstream. f_{HV} denotes the heavy vehicle adjustment factor, and N corresponds to number of lanes that are open during construction. Since HCM2000 only provides the method to calculate the work zone capacity for freeways, the work zone capacity for arterials have to be estimated based on the normal lane capacity and number of lanes that are remaining open during the construction.

Another requirement listed in section 9.5 is that *the tool shall be able to model the increase in accidents due to work zones.* Based on the review presented earlier in this chapter, the accident rate at work zones is assumed to be 30 percent higher than accident rates under normal conditions.

The requirements of Section 9.5 include *the calculation of the mobility impacts due to providing congestion and/or route information at SWZ by calculating the diversion.*

To calculate the benefits of the provision of delay or alternative route information at SWZ, a certain percentage of travelers are assumed to divert to alternative routes. This reduction in volume will result in lower calculated delays on the mainline. The defaults in this study are 5 percent of vehicles diverting when provided with delay information and 15 percent when provided with alternative route information. For those diverted vehicles, the alternative routes can be either the freeways or arterials, depending on the user-input percentage of diverted vehicles using freeways. The travel time on alternative routes can then be calculated as the weighted average of the travel time on the freeway and arterial alternative routes. The difference in vehicle-hour traveled between the scenarios without and with delay or alternative route information yields the total time savings. If the delay on alternative route is higher than that on the smart work zone segment or the capacity is exceeded then no diversion will be assumed.

Section 9.5 specifies that *the Tool shall evaluate the provision of speed advisory or queue warning on safety of smart work zone.*

It is assumed that the application of speed advisory reduces the speed variance at the work zones. The study by Garber and Gadiraju[110] reveals that the accident rate is proportional to the square of speed variance, which means that the provision of speed advisory messages can greatly reduce the number of crashes. Based on the extensive literature review, the default used in the developed tool are 10 percent reduction in the speed variance for speed advisory with a radar and a feedback VMS display, and 20 percent for speed advisory with an algorithm to calculate the safe speed. The resulting safety benefits are then obtained by multiplying the vehicle-mile traveled with the accident rate, accident rate reduction factor (calculated as a function of the reduction in speed variance), and corresponding accident costs.

The queue warning system is used to alert drivers that are approaching the slow moving vehicles ahead. The literature review indicates that the queue warning system can reduce the crash rate by 7 percent. The procedures to calculate the safety benefits resulting from queue warning system is similar to those for speed advisory system with the difference being the accident rate reduction factor.

Another type of smart work zone application is the dynamic lane merge system that regulates the merging actions of drivers by controlling the merging times and locations based on the traffic conditions detected by a set of sensors in the upstream segment of the lane-closed work zone. According to Section 9.5, *the Tool shall be able to evaluate the provision of dynamic lane merge information at SWZ on mobility and safety*. According to the studies by McCoy et al.[111] and Kang et al.,[112] the work zone throughput increases from 6.9 percent to 17.8 percent with dynamic lane merge.

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[110] Garber, N.J. and R. Gadiraju, "Factors Affecting Speed Variance and Its Influence on Accidents," AAA Foundation for Traffic Safety, Falls Church, VA. July 1988.

[111] McCoy, P.T., G. Pesti and P.S. Byrd, "Alternative Information to Alleviate Work Zone- Related Delays," Report SPR-PL-1(35)P513, University of Nebraska, Lincoln, 1999.

[112] Kangm,P, G.L.Chang and J. Paracha, "Dynamic Late Merge Control at Highway Work Zones: Evaluation Observations, and Suggestions," TRB 2006 Annual Meeting Proceedings, Washington, D.C., January 2004.

In this study, a 5 percent increase in the throughput is assumed for the application of dynamic lane merge system. Since the link travel time is a function of volume/capacity ratio according to the BPR curve, as the volume/capacity ratio changes, the resulting travel time varies. The difference in travel time generates the time savings due to the application of dynamic lane merge system. The impact of dynamic merge on safety is calculated by assuming an additional 40 percent reduction in the crash rate.

Based on the improved speed, the benefits of fuel savings and emission reductions can also be estimated using the modules described in Chapter 3 of this document.

Previous studies indicated that the smart work zone crash rate is 20 to 30 percent higher than the crash rate on the same segment without smart work zone. Thus, the work zone crash rate is assumed to be 1.3 more than that of a highway segment without a work zone.

Assuming that the SPVA can be reduced by 10 to 20 percent with speed advisory as reported in previous studies, the PDO crash rate can be estimated to be reduced by 5 percent on freeways and 2 percent for arterial based on the above equation. The studies reviewed above indicated that the reduction in injury and fatal crashes is expected to be higher than the reduction in PDO crashes due to SWZ, thus, the reductions in injury and fatal crashes will be assumed to be 10 percent for freeway and 4 percent for arterials.

The safety benefits will be calculated based on the rate of crashes, fatalities, and injuries with and without smart work zones as follows:

$$\text{Safety benefits} = \sum_i CCRi^* \; VD * WZCRi \qquad (9.2)$$

Where

CCR = Change in crash rate (accident per vehicle) due to smart work zone for severity i (fatality, injury, and property damage only),

VD = Change in volume due to diversion, and

WZCR = Work zone crash rate in accident per vehicle by accident severity i.

9.7 Implementation

The evaluation methodology of smart work zone is implemented as one of the applications in the ITS Evaluation Tool Cube catalog. By selecting this application, the user can identify the smart work zone as the ITS deployment to be evaluated, as shown in Figure 9-2.

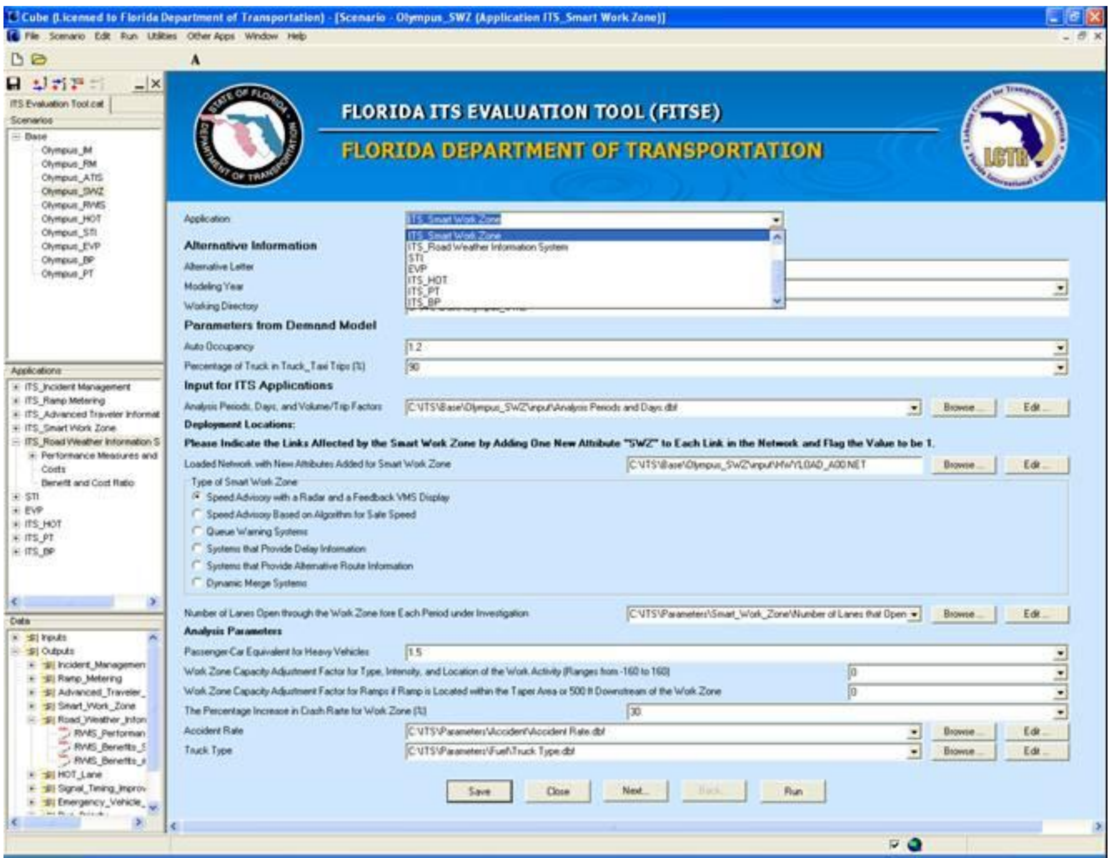


Figure 9-2 Selection of ITS Deployment Type

9.7.1 Modeling Structure

Similar to other ITS components, the modeling structure for smart work zone mainly consists of performance measures and benefits module, costs module, and benefit/cost ratio module. Since different types of smart work zone have different impacts, a separate sub-module is created for each type of smart work zone to evaluate the performance and benefits, which is illustrated in Figure 9-3. For detailed implementation procedures, users are referred to the catalog in Cube software.

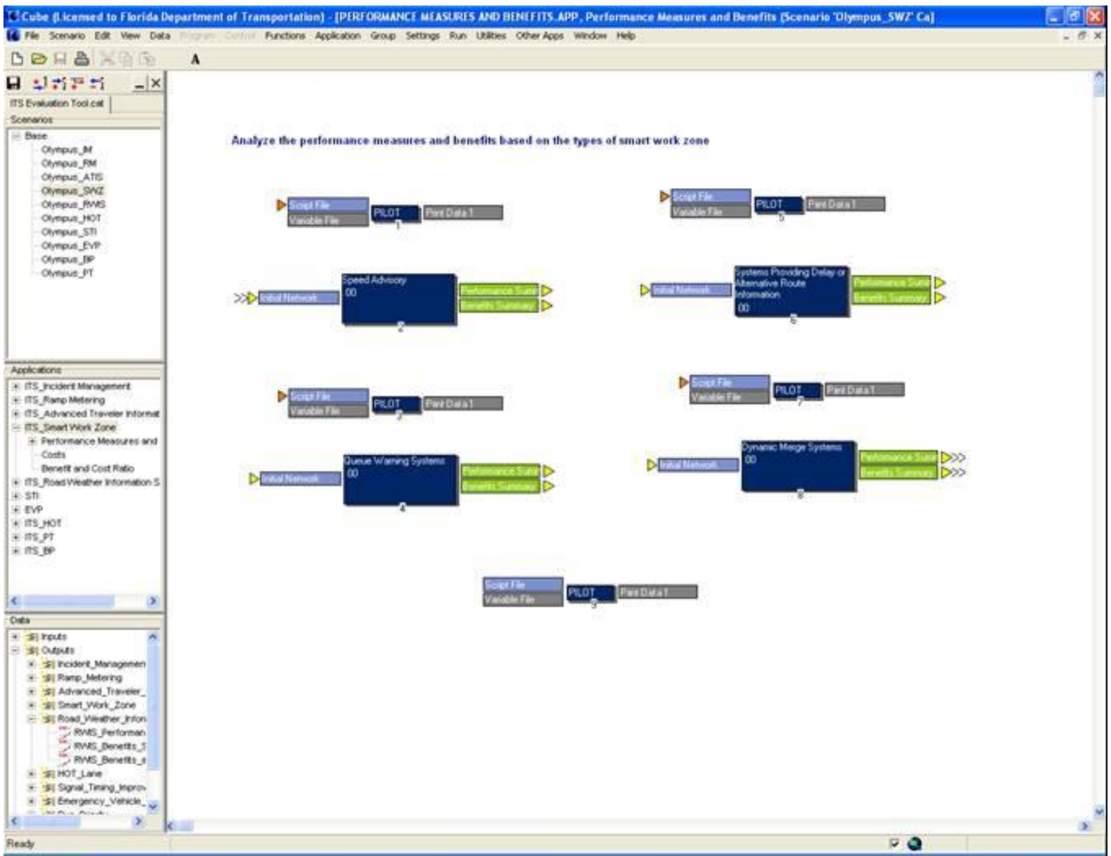


Figure 9-3 Modeling Structure for Smart Work Zones

9.7.2 User Interface

Figure 9-4 and Figure 9-5 show the user interface to input the parameters required to analyze smart work zones. Some of these parameters are general parameters that have been discussed in Chapter 5 of this document. This section presents a discussion of the parameters that are specific to the evaluation of smart work zones.

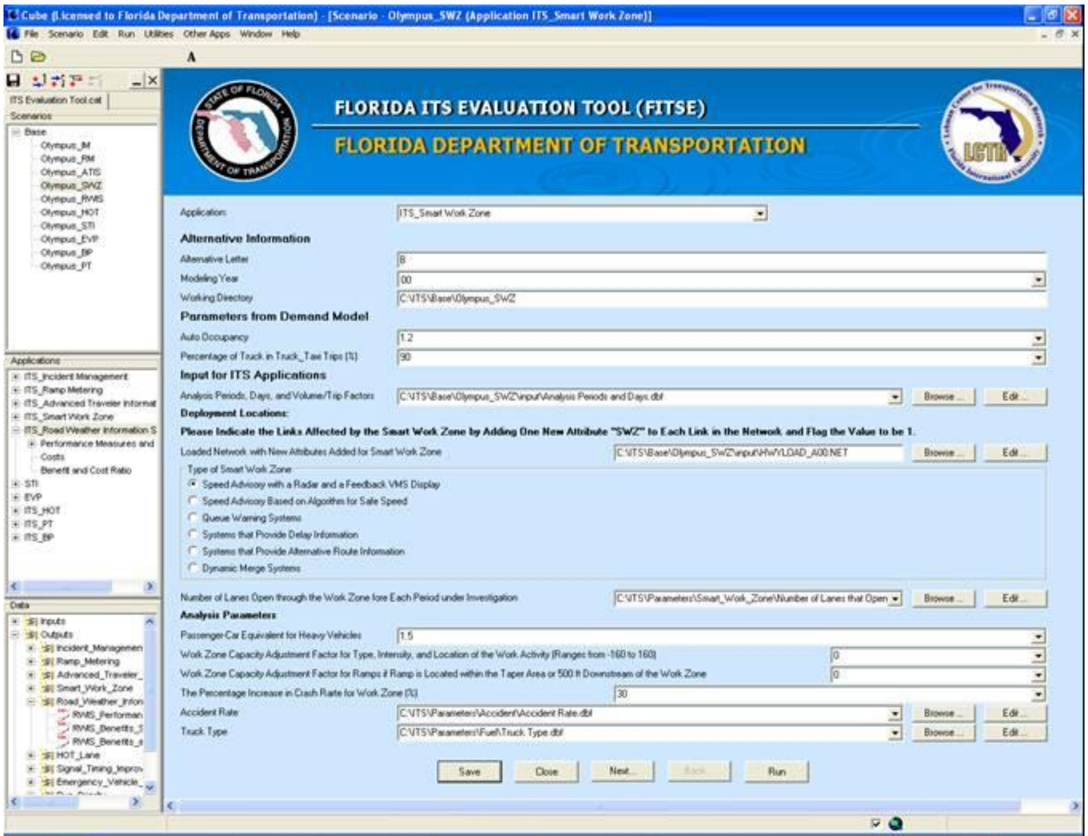


Figure 9-4 Interface to Input Parameters for Smart Work Zone

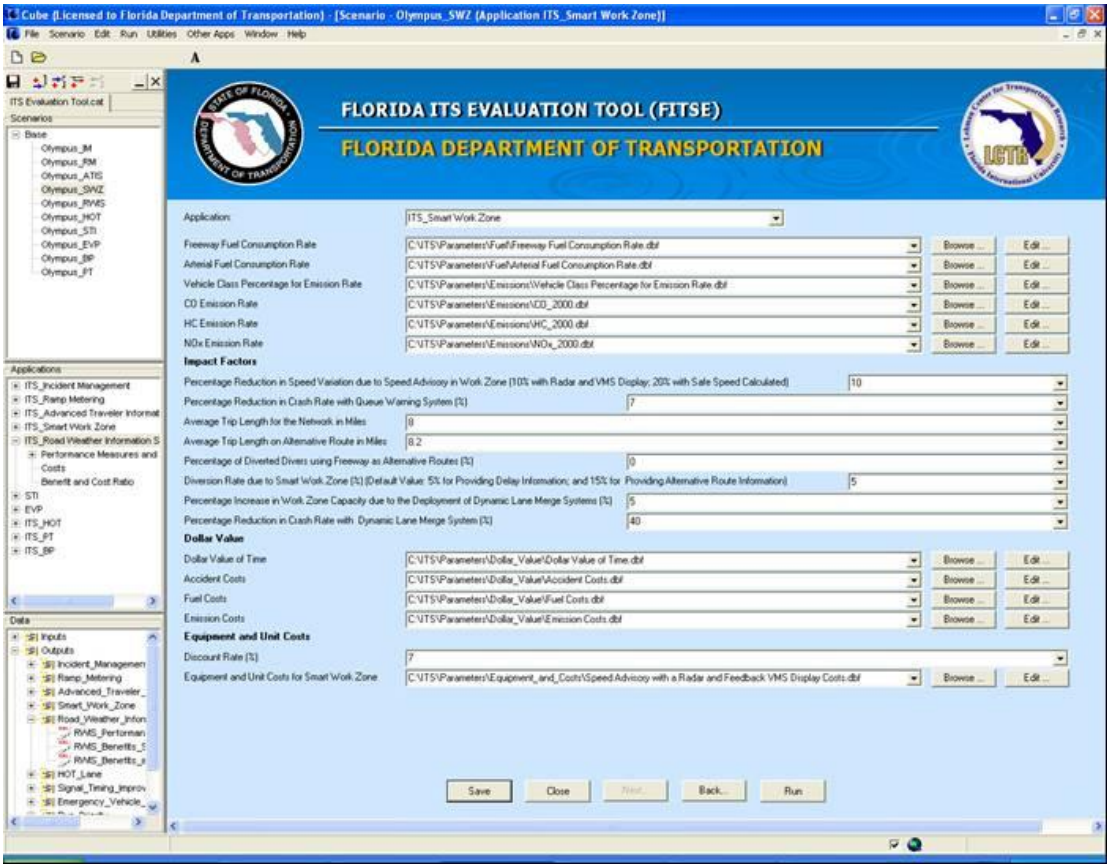


Figure 9-5 Interface to Input Additional Parameters for Smart Work Zones

- Deployment parameters:

  Deployment locations: the user can indicate the links within the coverage of smart work zone by adding one new attribute "SWZ" and assign the value of 1 of 1 to this attribute, as shown in

  - Figure 9-6.
  - Type of smart work zone.
  - Number of lanes that are open through the work zone.

- Analysis parameters:
  - Passenger-Car Equivalent for heavy vehicles.
  - Work zone capacity adjustment factor for construction type, work intensity, and location of the work activities.
  - Work zone capacity adjustment factor for ramps that are within the taper area or 500 ft downstream of the work zone.
  - Percentage increase in crash rate due to the work zone compared to the crash rate without work zone.

- Impact factors for different types of smart work zones:
  - Speed advisory system:

- ◆ Percentage reduction in speed variance (defaults = 10 percent for smart work zone with radar and VMS display, and 20 percent for smart work zone with an algorithm to calculate the safe speed).
- ◆ Queue warning system.
- ◆ Percentage reduction in crash rate (default = 7 percent).

- System providing the travel time or alternative route information:
  - ◆ Diversion rate due to this type of system (defaults = 5 percent for system providing delay information, and 15 percent for system providing alternative route information).
  - ◆ Average trip length on the mainline (default = 8 miles).
  - ◆ Average trip length on the alternative route (default = 8.2 miles).
  - ◆ Percentage of diverted vehicles using freeways (default = 0 percent).

- Dynamic lane merge system:
  - ◆ Percentage increase in work zone capacity (default = 5 percent).
  - ◆ Percentage reduction in crash rate (default = 40 percent).

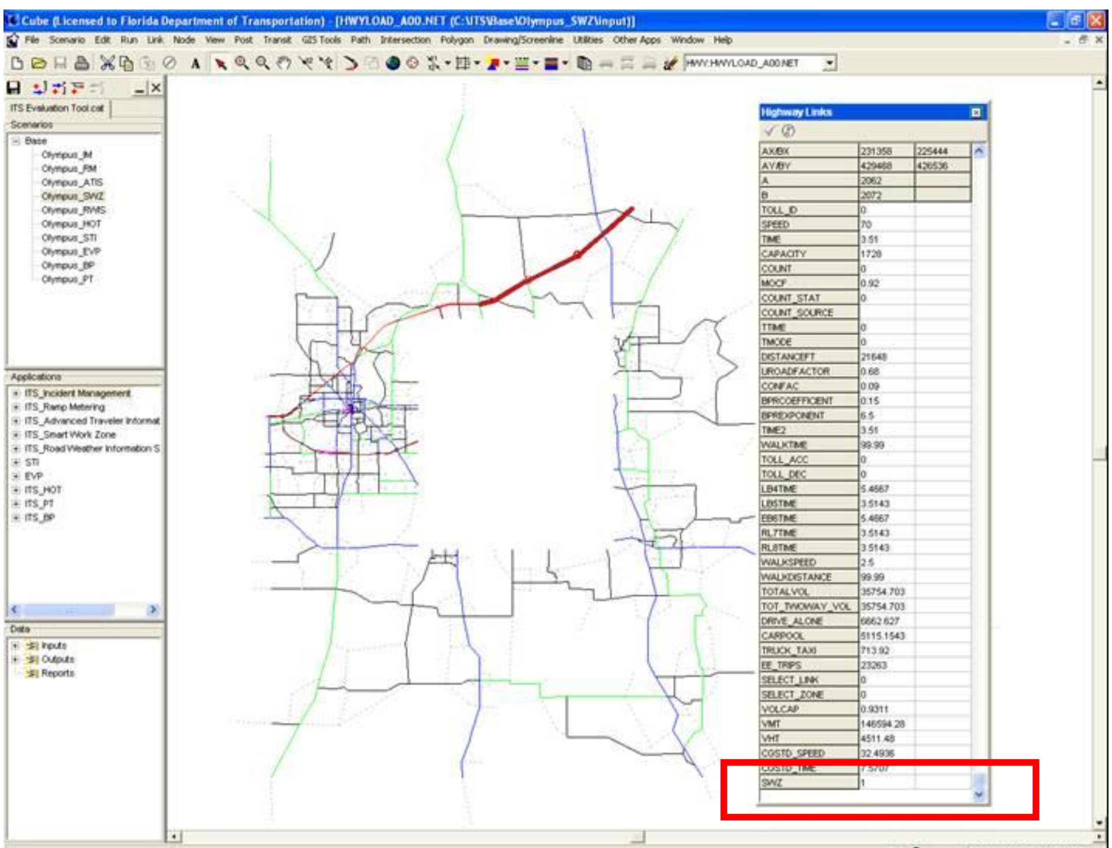


Figure 9-6 Identification of Smart Work Zone Deployment Locations

The analysis period inputs described in Chapter 5 and shown again here in Figure 9-7 have somewhat different meaning than other ITS applications. In other ITS applications, the "NO_OF_DAYS" refers to total number of days in one year included in the analysis, in most cases equal to the number of working days. In SWZ evaluation, this factor refers to the number of construction days that the SWZ is in operation for the identified. The user should input this as an estimated average value over all work zones in the SWZ deployment.

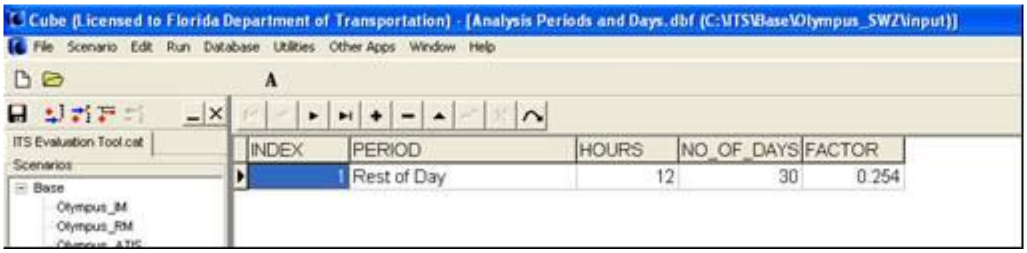


Figure 9-7 Analysis Period Inputs for SWZ

Figure 9-8 shows an input interface to enter the number of lanes that are open during the construction. The user may add or remove a study period by adding or deleting the corresponding record.

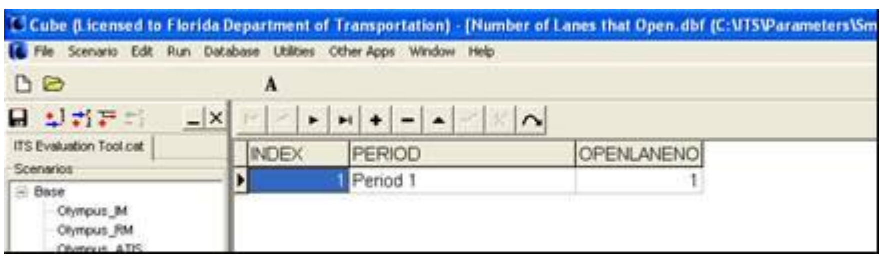
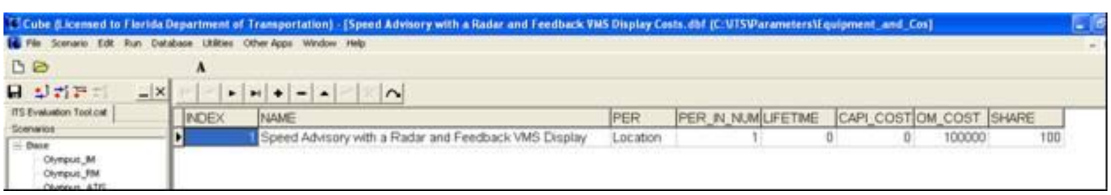


Figure 9-8 Input of the Number of Lanes Opened during Construction

Figure 9-9 displays the input file for the costs of smart work zone. There are six types of smart work zones that this tool can evaluate. Each of these types has its own equipment and costs. To view and edit the parameters for the specific work zone under consideration, the user can click the arrow on the right hand side of the input box for equipment and unit costs, and select the corresponding cost file from the list. Selecting the cost file and clicking the "Edit" button display a "dbf" file for the equipment and unit costs, as shown in Figure 6b. In this file, "NAME" is the name of the required equipment, "PER" indicates the unit of equipment, and "PER_IN_NUM" is the units expressed as a numeric value for the convenience of calculation. "LIFETIME" indicates the equipment lifetime. "CAPI_COST" and "OM_COST" are the capital costs, operating and maintenance costs, respectively. The column of "SHARE" determines the percentage of total costs spent on this project when sharing these equipment with other ITS applications. The user should input this as an estimated average value over all work zones in the SWZ deployment. This factor can be used to indicate that the SWZ is mobile and can be used at different locations in different times.

(a)



(b)

Figure 9-9 Interface for Inputting Equipment and Unit Costs for Smart Work Zones

9.7.3 Output Interface

As with other ITS applications, there are three standard output files generated for smart work zones: 1) performance summary, 2) benefits summary, and 3) benefits and costs summary (see Figure 9-10 to Figure 9-12). These three files are organized under the output category (smart work zone) in the data window. Figure 9-10 presents an example of the performance summary file. The contents of the performance summary depend on the type of smart work zone. Depending on the expected benefits of the specific SWZ, it can only include the number of accidents, or it can also consist of the travel time and accident number, as well as fuel consumption and emissions for each period without or with smart work zone.

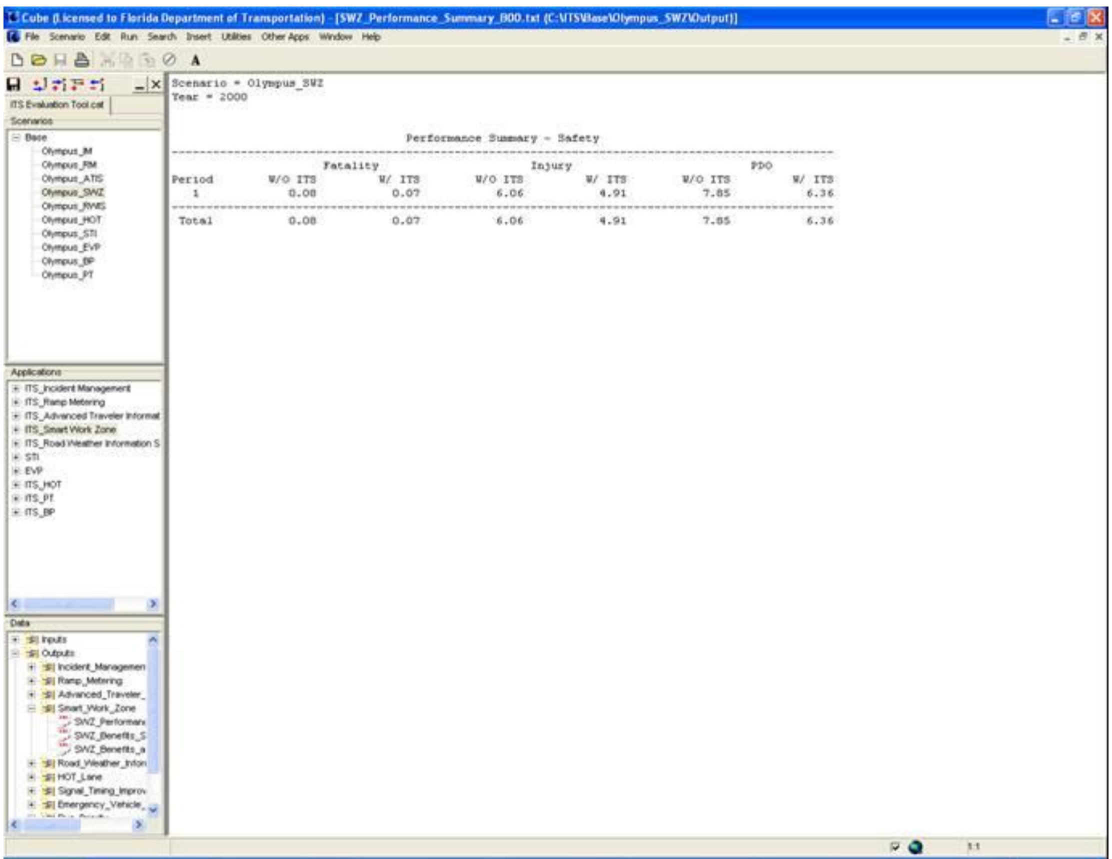


Figure 9-10 Performance Summary Output for SWZ

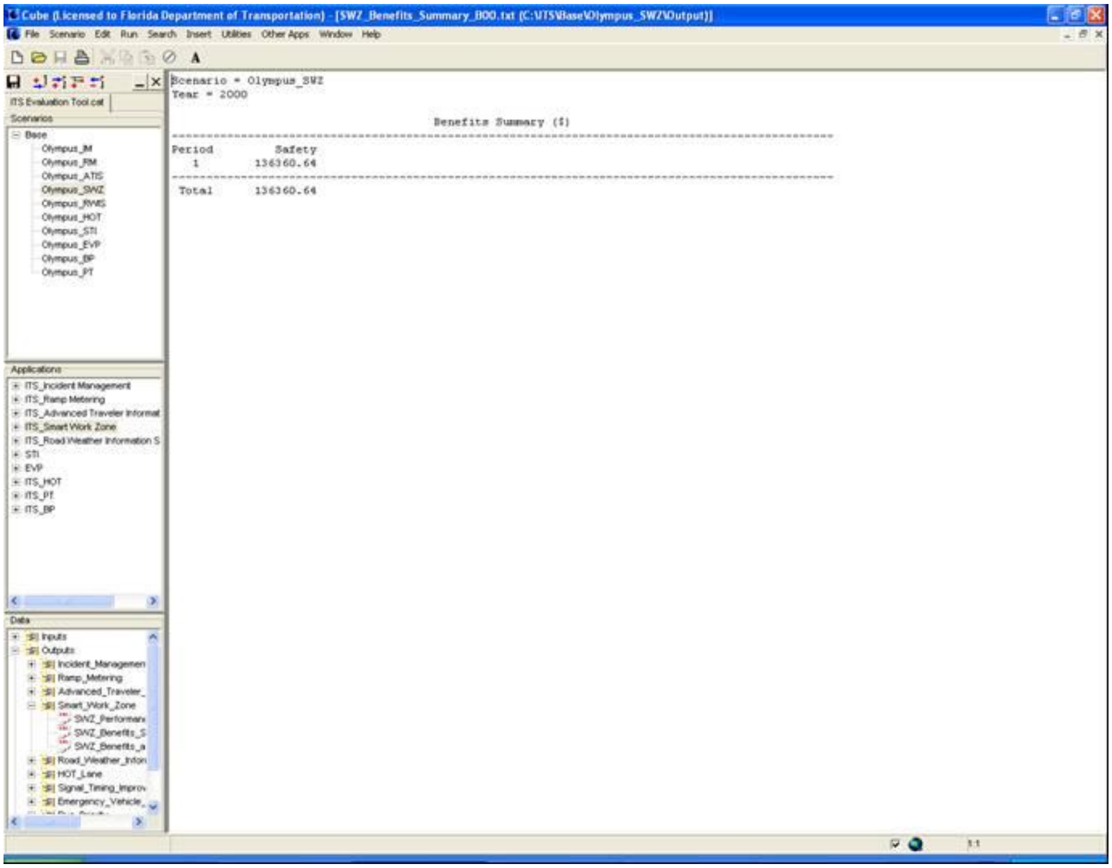


Figure 9-11 Benefit Summary Output for SWZ

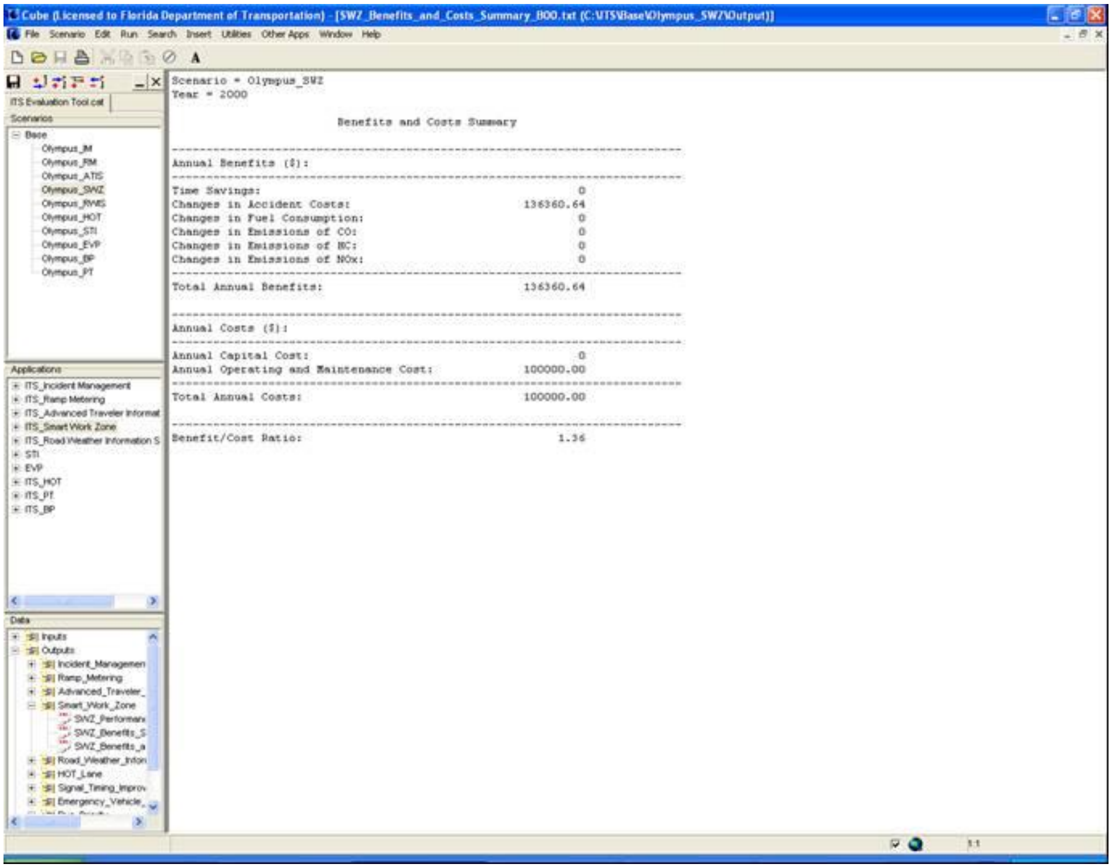


Figure 9-12 Benefit and Cost Summary Output for SWZ

10 Road Weather Information Systems

The Road Weather Information Systems (RWIS),[113] also called the Environmental Sensor Stations (ESS) in the field, is a communication system for data transfer, and central systems to collect and process data from ESS and possibly other sources. ESS stations measure atmospheric, pavement and/or water level conditions. Central RWIS hardware and software are used to process observations from ESS to develop current or forecasted weather conditions on the highway and display or disseminate road weather information. Travelers can use this information to make travel decisions; in addition, road operators and maintainers can use this information to support the decision-making process, particularly in snow/ice covered road maintenance activities.

10.1 Previous Approaches to Evaluation

IDAS does not have a RWIS evaluation model. ITSOAM has a RWIS evaluation module, but this model is not applicable to the Tool developed in this study, as described below.

10.1.1 RWIS Evaluation in the ITSOAM

Although ITSOAM has an RWIS evaluation module, this evaluation focuses on snowstorm and icy road conditions. With RWIS, Departments of Transportation can better manage their resources during winter weather emergencies. The cost of road treatment can be lowered with RWIS. RWIS also allows a more effective treatment, reducing the public's exposure to hazardous road conditions and reducing accidents. Properly timed salt spreading and plowing improve the traffic ability, which may result in delay savings, reduction in vehicle operational costs, as well as in lower emission. These impacts due to improved winter maintenance activities are considered in the ITSOAM evaluation of RWIS. Since, snowstorms are not an issue in Florida, the methodology employed in ITSOAM is not applicable to the Tool developed in this study.

10.1.2 Florida DOT Motorist Warning System[114]

The tropical climate in Florida typically causes heavy rainfall in the afternoon. A study of the Florida Turnpike/Interstate 595 interchange found that 69 percent of crashes on a two-lane, exit ramp occurred when the pavement was wet and that 44 percent of these wet-pavement crashes happened while it was raining. The wet-

[113] http://ops.fhwa.dot.gov/Weather/faq.htm

[114] Pisano, P. and L.C. Goodwin, "Best Practices for Road Weather Management," Version 2, Federal Highway Administration, May 2003.

pavement crash rate on this ramp was three times higher than the national average and nearly four times greater than the statewide average. The wet pavement and excessive travel speeds were considered the primary factors contributing to run-off-the-road crashes that occurred at the beginning of the sharp ramp curve. These conditions warranted the development and demonstration of a motorist warning system.

A sensor embedded in the road surface was used to monitor pavement condition (i.e., dry or wet). A microwave vehicle detector was also installed to record traffic volume and vehicle speed, and a precipitation sensor was mounted to verify rainfall events. A pole-mounted enclosure housed a remote processing unit (RPU), which was hard-wired to flashing beacons atop static speed limit signs. The RPU collected, processed, and stored traffic and pavement data from the sensors. When pavement moisture was detected, the RPU activated the flashing beacons to alert motorists that speeds should not exceed the posted limit of 35 mph (56.3 kph).

The warning system improved safety by reducing vehicle speeds and promoting more uniform traffic flow when the ramp was wet. In light rain conditions, the 85th percentile speed decreased by eight percent from 49 to 45 mph (78.8 to 72.4 kph). During heavy rain, there was a 20 percent decline in the 85th percentile speed from 49 to 39 mph (78.8 to 62.7 kph). Speed standard deviation was also reduced from 6.7 to 5.7 mph (10.8 to 9.2 kph) in light rain and from 6.1 to 5.6 mph (9.8 to 9.0 kph) in heavy rain. Thus, speed variance decreased by 8 to 15 percent, minimizing crash risk. Four crashes occurred during the first week of warning system activation. Three happened when the pavement was wet and one occurred during a rainfall. After this initial week, no crashes were reported during the nine-week evaluation period.

10.1.3 Idaho DOT Motorist Warning System[115]

The Idaho Department of Transportation (DOT) installed a motorist warning system on a 100-mile (161-kilometer) section of Interstate 84 in southeast Idaho and northwest Utah. This road segment was highly prone to multi-vehicle crashes when blowing snow or dust reduced visibility. From 1988 to 1993, poor visibility contributed to 18 major crashes involving 91 vehicles, 46 injuries, and nine fatalities.

The installed warning system provides advisory messages to motorists to influence driver behavior under adverse conditions. Road, weather, and traffic condition data are collected by sensor systems and transmitted to a central computer. ESS detects pavement conditions (i.e., dry, wet, or snow-covered), wind speed and direction, precipitation type and rate, air temperature, and relative humidity. Sensors with forward-scatter detection technology measure visibility distance. Inductive loop detectors record vehicle length (i.e., passenger car or truck), vehicle speed, and travel

[115] Pisano, P. and L.C. Goodwin, "Best Practices for Road Weather Management, Version 2, Federal Highway Administration," May 2003.

lane. Warnings of adverse conditions are posted on four roadside DMS. The central computer records sensor readings every five minutes.

A system evaluation conducted from 1993 to 2000 assessed changes in driver behavior due to road condition data displayed on the DMS. When traffic managers displayed condition data during high winds (i.e., over 20 mph or 32.2 kph), average speed variance was reduced and average vehicle speed decreased by 23 percent from 54.8 to 42.3 mph (88.1 to 68.0 kph). When high winds occurred simultaneously with moderate to heavy precipitation, average speeds were 12 percent lower. Under these conditions, the mean speeds were 47.0 mph (75.6 kph) without advisory information and 41.2 mph (66.2 kph) with warning messages. A 35-percent decline in average vehicle speed occurred when the pavement was snow-covered, wind speeds were high, and warnings were displayed.

10.1.4 Salt Lake City Fog Warning System[116]

In Utah, the ADVISE fog warning system was tested on a two-mile section of I-215. The ADVISE technology effectively reduced the average standard deviation of speed between vehicles by 22 percent. Prior to the deployment, the standard deviation was 9.5 mph. After the system was deployed and ADVISE messages were provided, the standard deviation decreased to 7.4 mph.

10.1.5 Automatic Fog System in the Netherlands[117]

An automatic fog warning system was installed on the A16 Motorway in the Netherlands. The system prompted drivers to slow down by 8 to 10 km/hr (5 to 6 mph) and drive at more uniform speeds. The study used the relation between the mean speed and number of accidents from previous studies to estimate the safety effects of RWIS. Based on this, it was estimated that a reduction in speed of 5 km/hr (3 mph) would result in approximately 15 percent fewer accidents.

10.1.6 RWIS Evaluation in Finland[118]

RWIS was evaluated on a 8.7 mile (14 km) test area in Finland. The system consisted of 36 variable speed limit signs, five DMS and two ESS. Each ESS measured wind speed and direction, air temperature, pavement and sub-surface temperature, humidity, precipitation rate and accumulation, and pavement condition. The western ESS nearest to the sea also measured precipitation type and visibility. The speed

[116] Perrin, J. et al., “Effects of Variable Speed Limit Signs on Driver Behavior During Inclement Weather,” Paper presented at ITE 2000 Annual Meeting. Nashville, Tennessee, 6-10 August 2000.

[117] Hogema, J. and V.H. Richard, “Evaluation of A16 Motorway Fog-Signaling System with Respect to Driving Behavior,” Transportation Research Board, TRR 1573, 1995.

[118] Yrjö, P.S. and J. Lähesmaa, “Weather Controlled Road and Investment Calculations, Southeastern Region,” Finnish National Road Administration. December 2000.

limits on this roadway section typically was 75 mi/h (120 km/h) in the summer. In the winter, recommended speed limits vary between 50 mi/h (80 km/h) and 62 mi/h (100 km/h) based on road and weather condition data collected from the ESS. The average yearly accident rate was projected to decrease by 8 to 25 percent. This impact on safety is due to lower average speeds when accident risk is greatest (i.e., when poor road conditions exist).

10.1.7 Influence of Adverse Weather Conditions on Safety

It takes longer to stop and it is harder to turn without skidding when the road is slippery. The Florida Commercial Driver License (CDL) Handbook 2007[119] states that wet roads can double stopping distance and recommends that drivers reduce speed by about one-third (e.g., slow from 55 to about 35 mph) on a wet road.

Although some drivers reduce their speeds during poor environmental conditions, this reduction is often accompanied by higher variation in speeds. In an analysis of speeds on a rural freeway in Idaho, Liang et al.[120] found that the standard deviation of speed doubles with fog and triples with snow. Although wet road surfaces will affect traction when attempting to stop, pass, or negotiate a curve or turn, most drivers do not reduce their speeds very much when traveling on wet roads.

In terms of the relationship between accidents and weather elements, a number of important studies have been conducted.[121] Based on these studies:

- Each year over 17 percent of fatal crashes, 22 percent of injury crashes, and 25 percent of property-damage-only crashes occur in the presence of adverse weather or slick pavement.[122]

- Most weather-related crashes happen on wet pavement and during rainfall. Seventy-six percent of weather-related crashes occur on wet pavement. Forty-eight percent happen during rainfall. Fourteen percent of weather-related crashes happen during snow or sleet. Thirteen percent occur on icy pavement. Ten percent of weather-related crashes take place on snowy or slushy pavement. Less than percent happen in the presence of fog.

[119] http://www.lowestpricetrafficschool.com/handbooks/cdl/en

[120] Liang, W.L., M. Kyte, F. Kitchener and P. Shannon, "The Effect of Environmental Factors on Driver Speed: A Case Study," Paper No. 981397, Transportation Research Board, Washington, DC, January 1998.

[121] Ivey *et al.*, 1981; Jovanis and Delleur, 1981; Mori and Uematsu, 1967; Snyder, 1974

[122] "Based on NHTSA data, Ten-year averages from 1995 to 2004 analyzed " by Mitretek Systems.

10.1.8 Factors Affecting Speed Variance and ITS Influences on Accidents[123]

A major influence on speed variance is the difference between the design speed and the posted speed limit. Most research results show that higher speed variance is usually associated with higher accident rates. For example, Pisarski[124] found a significant statistical relationship between speed variance and accident rate. A study in Canada on speed and accidents[125] also found that speed variance may be an important factor in accidents. Cerrelli[126] concluded that accident rates increased as the speed of the vehicle deviated from the average speed of the traffic.

Garber and Gadiraju[127] developed models that predict the influence of speed variance on accident rates on different categories of highways. The model obtained from the regression analysis for interstate highways is $ACCRT = 43.2+0.00347(SPVA)^2$ and for arterial highways is $ACCRT = 168+0.00273(SPVA)^2$, where ACCRT is accident rate in number of accidents per 100 million vehicle miles of travel and SPVA is speed variance. These models indicate that accident rates increase as speed variance increases. The models were then tested on critical locations where the accident rate is higher that the critical value. The hypothesis is if the location is hazardous then the difference between the design speed and the posted speed limit is either less than 5 or greater than 10 mph. After applying the test on 124 locations 81 percent of the observations satisfied the conditions of the hypothesis. Hence, the test proved that accidents do increase with an increase in speed variance.

10.1.9 Assessment

As reported above, IDAS does not have a module to evaluate RWIS and the ITSOAM evaluation of RWIS is not relevant to this study since it deals with the improvements to winter (snow/ice maintenance). No studies have been found in the United States to evaluate the RWIS effect on safety. Some studies have shown that the speed and/or speed variance can be reduced by 8 percent to 23 percent depending on the severity of the weather events. Studies have also shown that the standard deviation of speed may be decreased by 8 percent to 22 percent due to RWIS. Studies from Finland and the Netherlands projected that the crash rates could be reduced by 8 percent to 25 percent

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[123] Garber, N.J. and R. Gadiraju, “Factors Affecting Speed Variance and Its Influence on Accidents,” Transportation Research Record 1213, Transportation Research Board, National Research Council, Washington D.C., 1989.

[124] Pisarski, A.E., “Deep-Six 55 Reason Foundation,” Vol.17, No.6, Nov. 1986, pp.32-35.

[125] “Speed and Accidents: A preliminary Report,” Ministry of Transport and Communications, Ontario, Canada, 1974.

[126] Cerrelli, E.C., “Safety Consequences of Raising the National Speed Limit From 55mph to 60mph,” NHTSA, U.S Department of Transportation, 1981.

[127] Garber, N.J. and R. Gadiraju, “Factors Affecting Speed Variance and Its Influence on Accidents,” AAA Foundation for Traffic Safety, Falls Church, VA, July 1988.

due to RWIS. It has been found that 17 percent of fatal crashes, 22 percent of injury crashes, and 25 percent of property-damage-only crashes occur in the presence of adverse weather or slick pavement. It can be assumed that 75 percent of these occur during rain, fog, or wet pavement. Thus, the above percentages become 13 percent, 17 percent, and 18 percent for PDO, injury, and fatality under rain and wet pavement conditions.

Previous studies have lead to a general role that 1 km/hr drop in speed can reduce crash rate by 3 percent[128] assuming that a decrease in speed by 10 percent results in a drop of about 6 mph (9.6 km/hr) for freeways and 4 mph (6.5 km/hr) for arterials. Using a conservative assumption of 2 percent reduction per 1 km/hr reduction in speed, it can be estimated that the reduction in wet weather crashes is about 20 percent for freeways and 13 percent for arterials. In this study, the reduction in crashes due to adverse weather conditions should be assumed to be 15 percent for freeways (10 to 20 percent) and 10 percent for arterials (5 to 15 percent).

10.2 Cost

Texas DOT implemented a RWIS in Abilene, Texas. The RWIS includes roadside surface and atmospheric sensors, remote processing units, and a central processing unit with road weather software. It was reported[129] that an ESS station cost in 1997 was $42,000 and the annual operation and maintenance (O&M) cost was $5,460 per remote site.

The USDOT RITA cost database includes cost estimates of ESS station from $29,000 to $48,000 for initial costs, and $1,900 to $4,100 for annual O&M costs. The Florida specific parameters project estimated the cost to be from $34,000 to $68,000. In this study, this range will be used with a default value of $50,000. The annual O&M cost will assume to range between $3,000 and $6,000, with a default value of $5,000. The user needs to specify the number of RWIS per implementation.

10.3 Requirement Analysis

This section lists the requirements for the evaluation of RWIS:

- The user shall be able to select the links that will be affected by RWIS.
- The Tool shall be able to estimate the weather related crashes on the segment based on default parameters.

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[128] Lynam, D. and T. Hummel, "The Effect of Speed on Road Deaths and Injuries: Literature Review," Prepared by the Swedish National Road Administration by TRL Limited, Stockholm, Sweden, 2002.

[129] McKeever, M. et al, "A Life Cycle Cost-Benefit Model for Road Weather Information Systems," Paper presented at the 77th Annual Meeting of the Transportation Research Board, Washington, DC, January 1998.

- The user shall be allowed to change the default parameters used to calculate the crashes due to adverse weather based on local data.

Analysis: Weather-related crashes will be calculated by multiplying the total crash frequency calculated for the highway segment by the percentages of crashes that occur in wet conditions. It will be assumed that 13 percent, 17 percent, and 18 percent of PDO, injury, and fatality occurs under rain and wet pavement conditions These percentages will be used as defaults in the Tool to calculate crash rates under wet and rain conditions based on the total crash rate.

Analysis: This is important to reflect higher curvature locations or higher rain fall intensity. For example, on the Florida Turnpike/ I-595 interchange, 69 percent of crashes on a two-lane, exit ramp occurred when the pavement was wet and only 44 percent of these wet-pavement crashes happened when it was raining.

- The Tool shall be able to calculate the reduction in rain, fog, and wet weather crash rates assuming default values that can be changed by he user

Analysis: As recommended in the assessment section above, the reduction in crashes due to adverse weather conditions should be assumed to be 15 percent for freeways (10 to 20 percent) and 10 percent for arterials (5 to 15 percent).

10.4 Methodology

As discussed earlier in this chapter, RWIS improves safety by reducing vehicle speeds and promoting more uniform traffic flow. Considering the tropical climate in Florida that typically causes heavy rainfall in the afternoon, the evaluation of RWIS in this study focuses on the wet pavement and rain related crashes instead of snowstorm or icy roadway related crashes. The associated safety benefits of RWIS can be evaluated by considering the percentage of crashes under rain and wet pavement conditions and a crash reduction factor that applied to these crashes when the RWIS is implemented. It is assumed that 13 percent, 17 percent, and 18 percent of fatalities, injuries, and PDO occur under rain and wet pavement conditions, respectively. Furthermore, the reduction in crashes is assumed to be 10 to 20 percent for freeways with a default of 15 percent, and 5 to 15 percent for arterials with a default value of 10 percent.

10.5 Implementation

The evaluation methodology of road weather information system is implemented as one of the applications in the ITS Evaluation Tool Cube catalog. By selecting this application, the user can identify the ITS deployment to be evaluated as a road weather information system (RWIS), as shown in Figure 10-1.

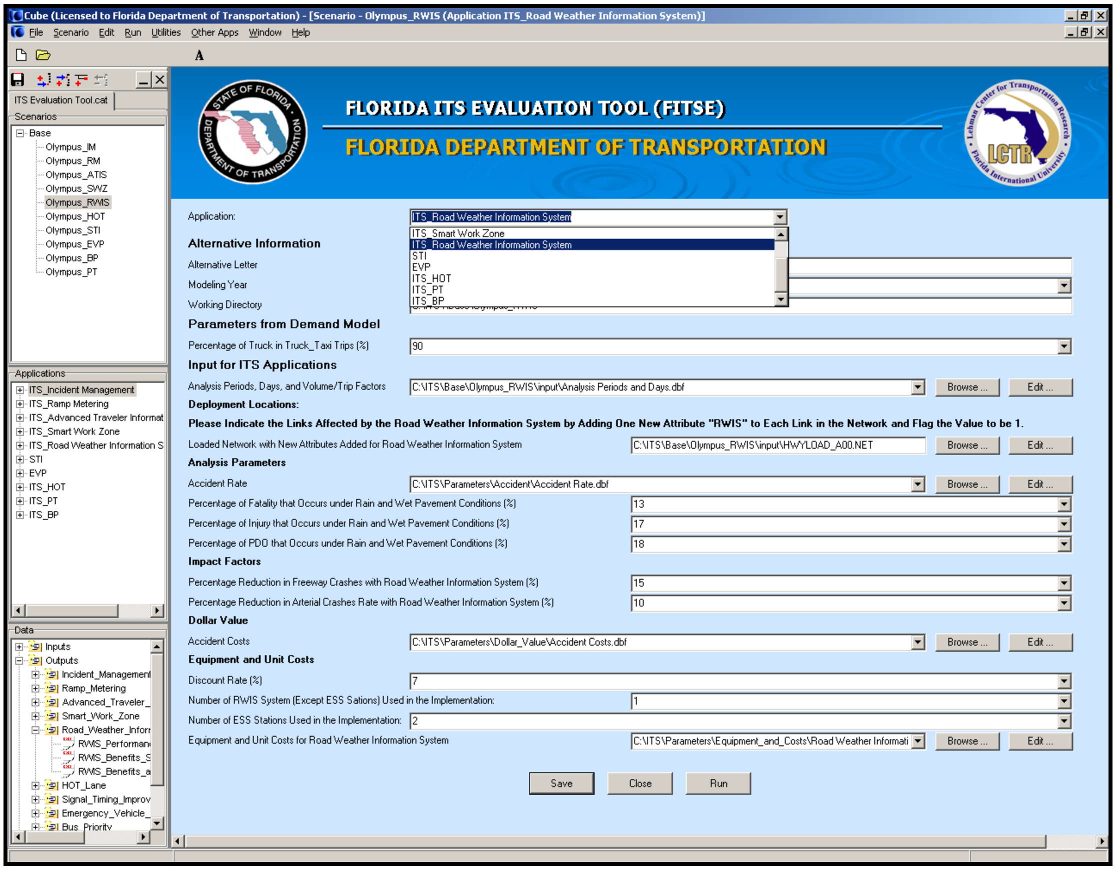

Figure 10-1 Selection of ITS Deployment Type as RWIS

10.5.1 Modeling Structure

As with other ITS deployment types, three modules are implemented in Cube to evaluate the road weather information system deployments: 1) performance measures and benefits, 2) costs, and 3) benefit/cost ratio modules. Figure 10-2 displays the procedure for the calculation of the safety benefits of RWIS. For more detailed understanding of the implementation procedures, the users are referred to the ITS Evaluation catalog implemented in the Cube software.

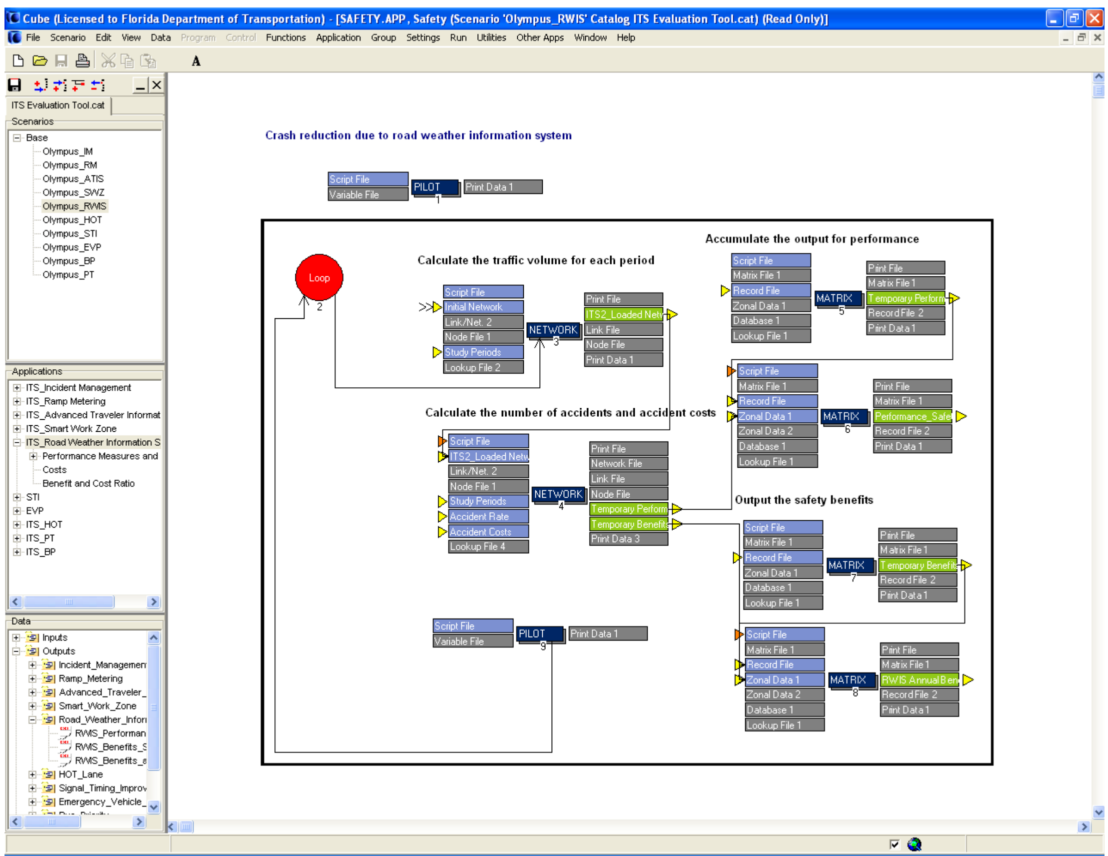

Figure 10-2 Modeling Structure for RWIS Evaluation

10.5.2 User Interface

Figure 10-3 shows the user interface to view and enter the input parameters required for evaluating RWIS. The general parameters were discussed in Chapter 5. This section discusses the parameters that are specific to RWIS calculation.

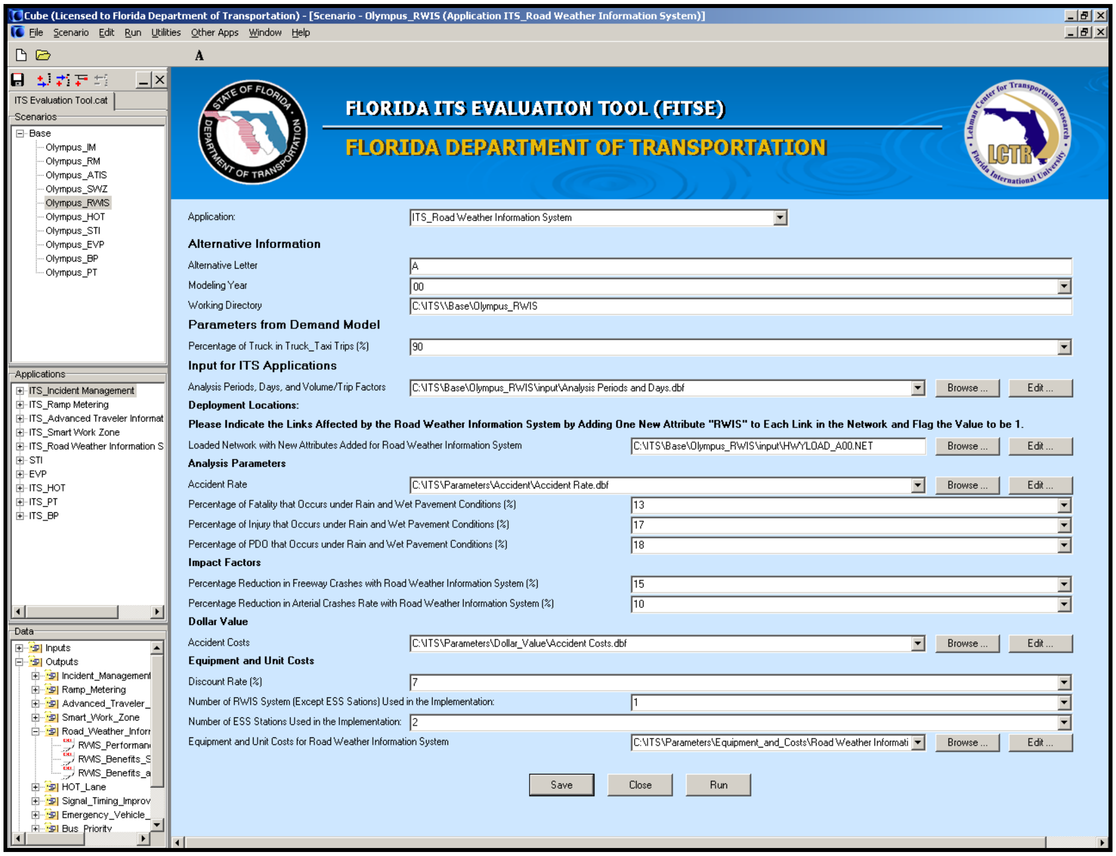

Figure 10-3 User Input Interface for RWIS

- Deployment locations: The user can indicate the links within the coverage of RWIS by adding one new attribute "RWIS" and assign the value of 1 to this attribute. As shown in Figure 10-4, the user can specify the deployment locations of road weather information system by first adding one new attribute "RWIS" to the links. If the link has a value of "1" for this attribute, this link is within the coverage by RWIS, otherwise, it is not covered by RWIS.

- Analysis parameters:

Accident rate (see

  - Figure 5-11).
  - Percentage of fatalities that occur under the rain and wet pavement conditions (defaults = 13 percent).
  - Percentage of injuries that occur under the rain and wet pavement conditions (default = 17 percent).
  - Percentage of PDO that occur under the rain and wet pavement conditions (default = 18 percent).

- Impact factors:
  - Percentage reduction in freeway crashes with RWIS (default = 15 percent).

- Percentage reduction in arterial crashes with RWIS (default = 10 percent).

- Equipment and costs:
  - Number of RWIS system (except the ESS stations) needed in the implementation (default = 1).
  - Number of ESS stations needed in the implementation (default = 1).

Below is a more detailed explanation for some important input.

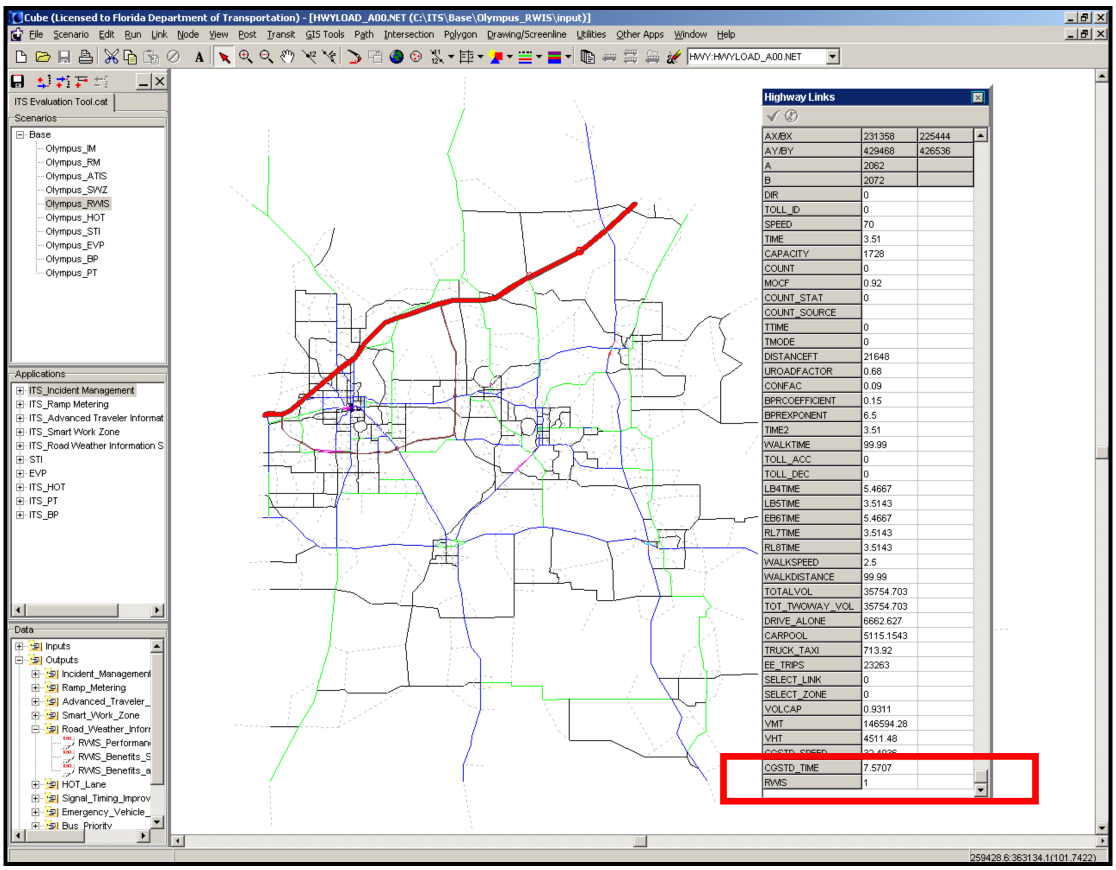

Figure 10-4 Deployment Locations of RWIS

The input file for equipment and unit costs of road weather information system is shown in Figure 10-5. Similar to the other ITS applications, “NAME” describes the equipment required, “PER” is units for equipment, and “PER_IN_NUM” is the units expressed as the numeric value for the convenience of calculation. “LIFETIME” indicates the equipment lifetime. “CAPI_COST” and “OM_COST” are the capital costs, operating and maintenance costs, respectively. The column of “SHARE” specifies the percentages of costs spent on this deployment when sharing these equipment with other ITS applications.

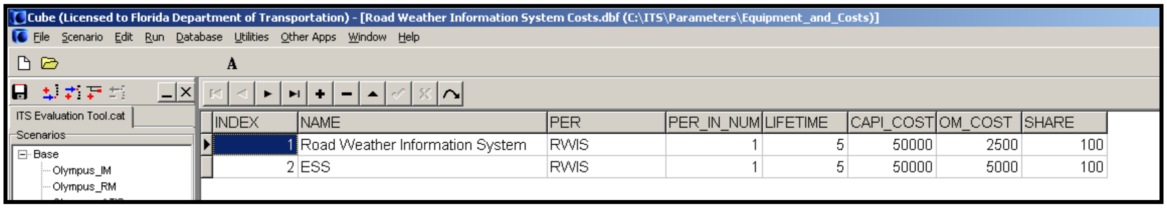

Figure 10-5 Equipment and Unit Costs for RWIS

10.5.3 Output Interface

As with other ITS applications, three standard output files are generated for road weather information system: performance summary, benefits summary, and benefits and costs summary. These three files are organized under the output category (road weather information system) in the data window. Examples of these files are shown in Figure 10-6 to Figure 10-8.

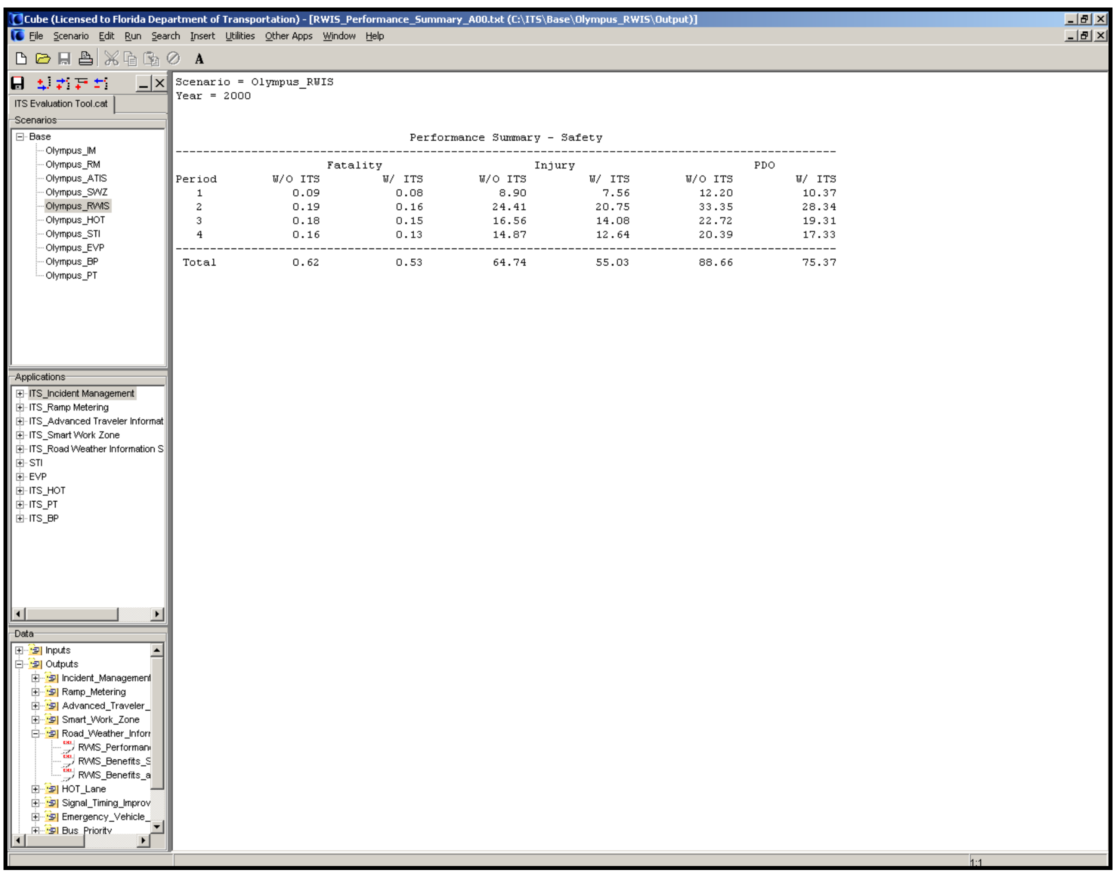

Figure 10-6 Performance Summary Output for RWIS

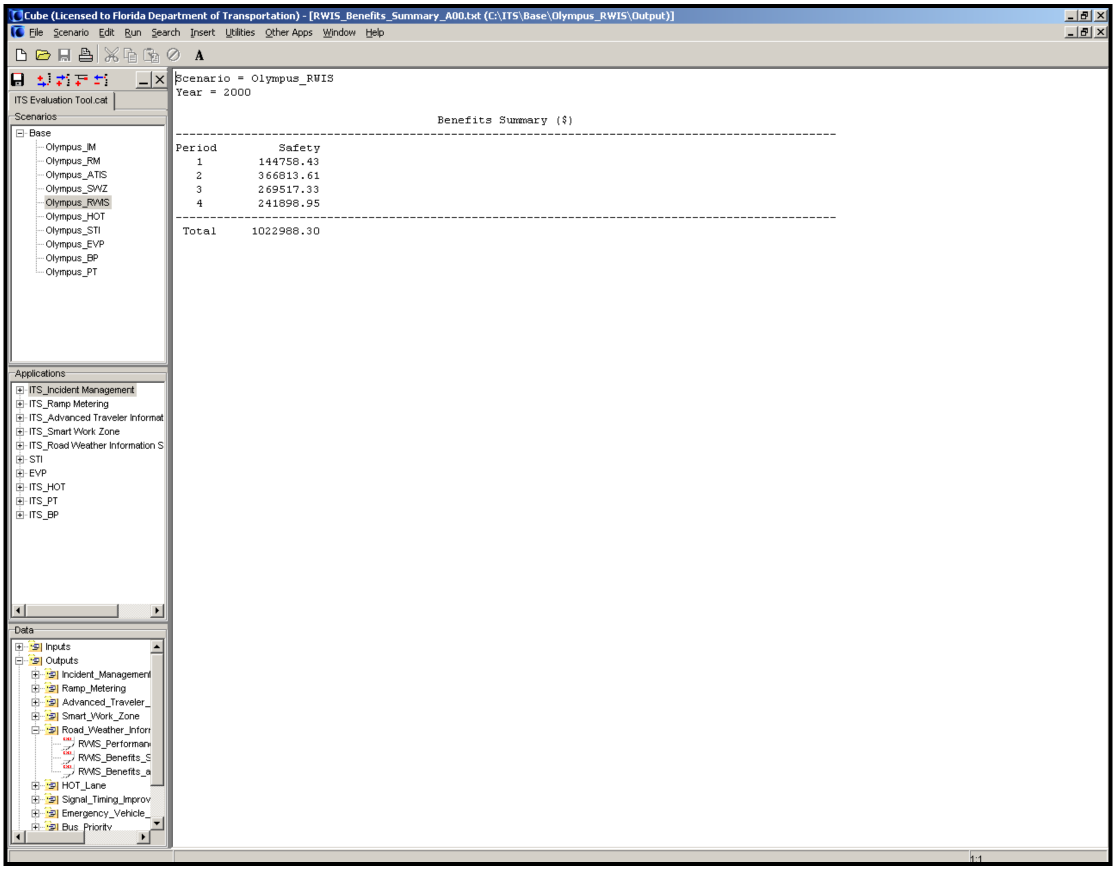

Figure 10-7 Benefit Summary Output for RWIS

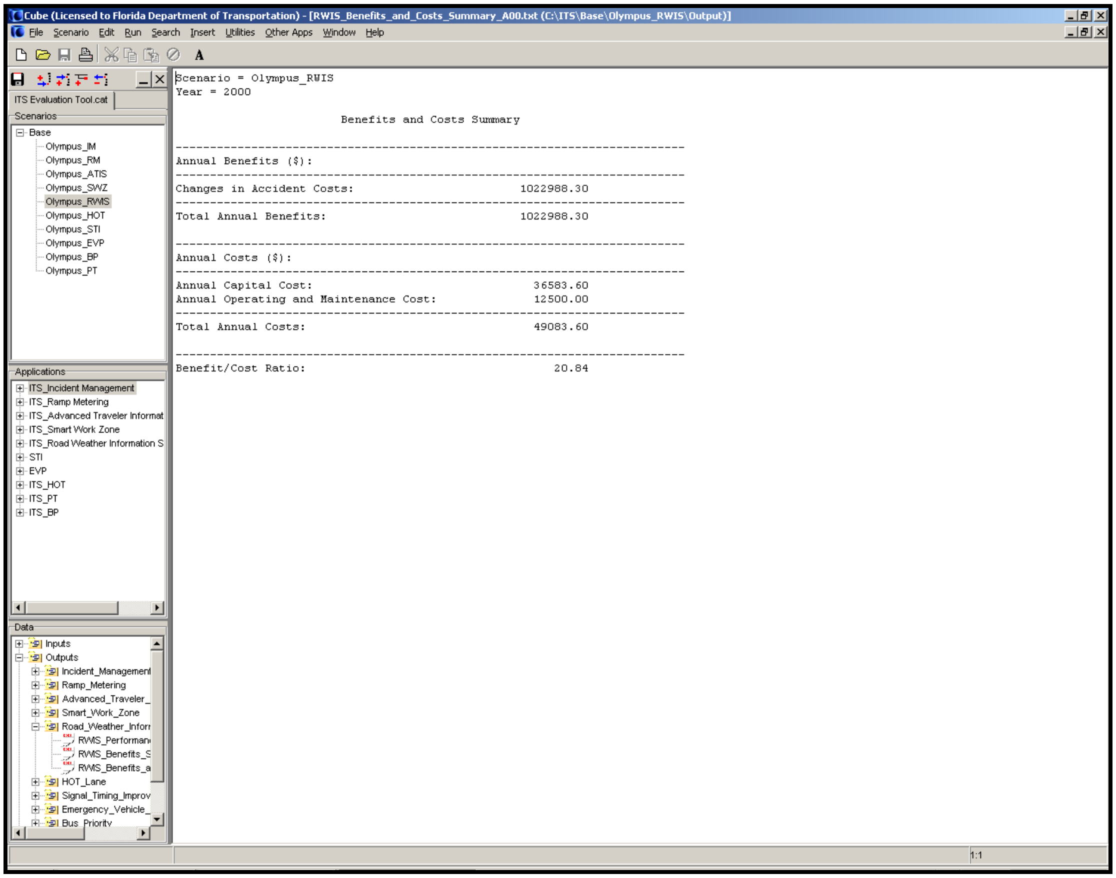

Figure 10-8 Benefit-Cost Summary Output for RWIS

11 Emergency Vehicle Signal Preemption

Traffic signal preemption is a type of system that allows the normal operation of traffic lights to be preempted, often to assist emergency vehicles. The most common use of these systems is to allow emergency vehicles priority by changing traffic signals in the path of the vehicle to green and stopping conflicting traffic. The objectives of emergency vehicle preemption include reducing emergency response time, improving safety and stress levels of emergency vehicle personnel, and reducing accidents involving emergency vehicles at intersections.

11.1 Previous Approaches to Evaluation

This section presents a review of tools and studies that address the evaluation of emergency vehicle priority with traffic signal preemption.

11.1.1 IDAS Methodology

IDAS assumes that the application of Emergency Vehicle Signal Priority results in a 19 percent increase in the speed of the links with priority, while the effects on the non-priority cross-links are ignored. The difference between the VHT before and after the implementation of signal priority (calculated based on the increase in speed) is multiplied by the percentage of the link volumes that is composed of emergency vehicles to calculate the travel time savings. IDAS assumes the following:

- A default increase of 19 percent in priority link speed based on the evaluation results from Denver, Houston, and Minneapolis.
- Emergency vehicles consist of 0.1 percent of link traffic volumes.
- The value of time savings associated with the emergency vehicle signal priority is assumed to be 30 times greater than the normal time value.

The resulting economic benefit is obtained by multiplying the emergency vehicle VHT savings by the value of time that the emergency vehicles save (30 times the normal value). IDAS assumes that this ITS component has no effects on safety, environment, energy, or travel time for other types of vehicles.

11.1.2 Reported Impacts on Other Movements

A paper by McHale and Collura[130] presented an improvement to the method used by the IDAS sketch planning tool to assess the impacts of emergency vehicle preemption. The method used in the IDAS program only considers travel speed

[130] McHale, G.M. and J. Collura, "Improving Emergency Vehicle Traffic Signal Priority System Assessment," A Paper Presented at the TRB Annual Meeting, Washington, D.C., January 2003.

improvements for emergency vehicles and does not consider the impacts on other travelers.

The CORSIM micro-simulation tool was used to model traffic signal preemption for emergency vehicles along a signalized seven intersection long arterial. Benefits were quantified in terms of reduced travel time and increased travel speed. Recommendations were made to incorporate the estimation of non-emergency vehicle travel time impacts into the current IDAS methodology. Based on the simulation results, the time impacts were relatively small, ranging from a 1.1 percent to 3.3 percent travel time increase for a one-hour analysis period and a 0.6 percent to 1.7 percent travel time increase for a two-hour analysis period. The proposed modification by McHale and Collura is shown in Table 11-1.

Table 11-1 Recommended Values for Emergency Vehicle Impacts on Travel Time of Conflicting Movements

Approach	**Congestion Level**		
	Low	Medium	Heavy
Main Street Non Preemption Path	1.1%	2.4%	3.3%
Cross Street Non Preemption Path	1.3%	1.9%	2.0%

11.1.3 Indiana Study

Nelson and Bullock[131] reported on a case study that used the CORSIM micro-simulation to examine the impact of emergency vehicle preemption on closely spaced arterial traffic signals. The study was conducted on a principal arterial on the East side of Lafayette, Indiana, and examined four coordinated intersections using seven preemption paths and three transition algorithms (smooth, add, and dwell). The number of preempts varied from one to three for each simulation period. The results indicated that a single preemption call with the smooth transitioning algorithm performed the best with most scenarios and paths. When multiple emergency vehicles preempt signals at closely spaced intervals, the impact of preemption was more severe. In the most severe case, delays in the order of 20-30 seconds per vehicle were computed.

[131] Nelson, E. and D. Bullock, "Impact Evaluation of Emergency Vehicle Preemption on Signalized Corridor Operation," Paper presented at the 79th Annual Transportation Research Board Meeting, Washington, DC. 2000.

11.1.4 Impacts on Emergency Vehicle Crashes

A 1977 study[132] examined emergency accident data rates before and after the installation of an emergency vehicle traffic signal preemption system in St Paul, Minnesota. In 1969, 28 Opticom emergency systems were installed. Between 1969 and 1976, the accident rate for emergency vehicles decreased by 70.8 percent. During this same period, the number of signalized intersections increased from 274 to 308 and the number of intersections equipped with signal preemption grew from 28 to 285. During this period, the number of emergency vehicle crashes decreased from the 1967 high of eight to an average of 3.3 per year in the latter years of the study. The performance measure, emergency vehicle crash per alarm, was used to compare before and after results. Results indicate that the number of emergency vehicle crashes per alarm continued to improve despite increases in the number of alarms and volume of traffic.

The Risk Management Office of the city of Plano, Texas, conducted a study that indicated that 22 EV crashes occurred from 1981 to 1983. Of these 22 crashes, seven occurred at signalized intersections and may have been preventable had preemption been in place. Over the 20 years since the installation of emergency vehicle preemption, only four crashes have involved emergency vehicles at intersections. In three of these crashes, the failure of the passenger vehicle to stop for the system's red signal display caused the crash and the fourth was caused by driver error in the emergency vehicle. [133]

11.1.5 Denver Evaluation

The city of Denver Department of Safety study[134] reported on the impacts of emergency vehicle response times with the implementation signal preemption in the City of Denver, Colorado, between 1977 and 1978. The area of study included 75 signalized intersections and three fire stations. Results from the before and after comparisons indicated that emergency vehicle response times decreased by 14 to 23 percent, saving approximately 70 seconds per response, on a typical response that spanned three to six signalized intersections.

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[132] Fire Chief, Department of Fire and Safety Services, St. Paul, Minnesota, "Emergency Vehicle Accident Study," A letter written from the Fire Chief to a City Councilman, 1977.

[133] "Traffic Signal Preemption for Emergency Vehicles," A Cross-Cutting Study, Produced by the U.S. Department of Transportation, Washington, D.C., January 2006.

[134] City of Denver Department of Safety, "Time Study on the Effectiveness of the Opticom Traffic Control System," Report Prepared for the City of Denver by the Denver Department of Safety, FHWA Report No. D-ORTS/78.5.

11.1.6 Impact of Emergency Vehicle Times

In defining service needs of Fire and Rescue agencies, jurisdictions consider fire flashover times (Figure 11-1) and survival rates for cardiac patients (Table 11-2) along with local conditions, including development density and loss potential. Emergency Vehicle Preemption can lead to improvements in emergency vehicle response times, increasing the effective service radius of a single station.

For effective fire suppression, units must be able to apply water to a fire prior to the point of flashover, which, for most residential construction, occurs anywhere from 4 to 11 minutes after the fire begins. The flashover is the point at which the room bursts into flame.

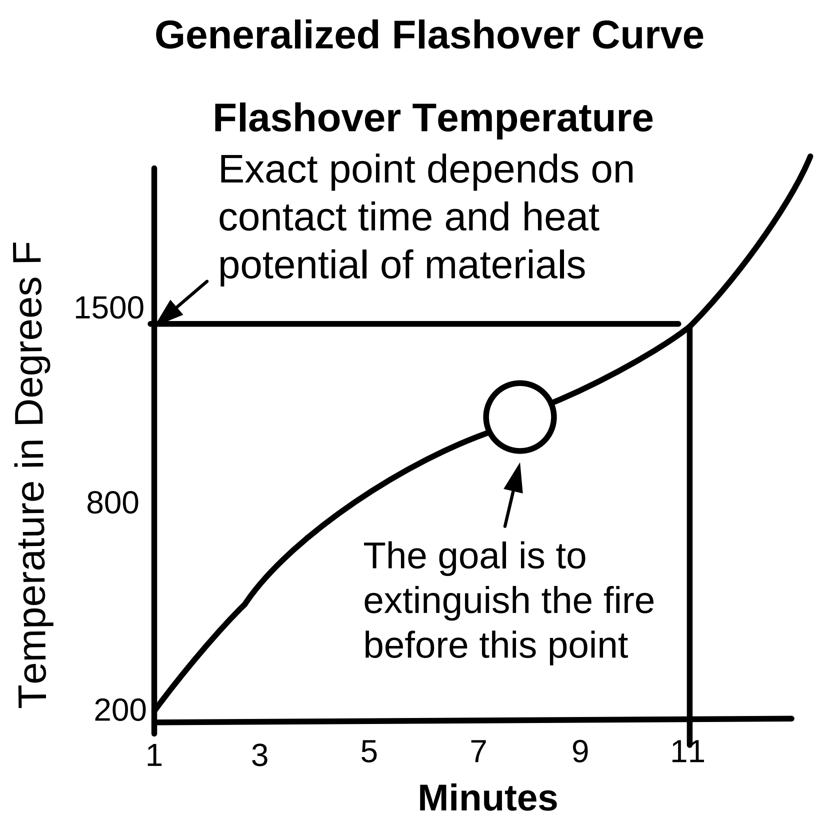


Figure 11-1 Generalized Flashover Curve for Residential Construction[135]

[135] "Structure Fire response Times", Topical Fire Research Series, Volume 5 - Issue 7, January 2006

Table 11-2 Cardiac Arrest Survival Factors as a Function of Time[136]

Time Until Defibrillations	Survival Chances
With every minute…	Chances are reduced by 7 – 10%
After 8 minutes…	Little chance of survival

Effective rescue programs are generally based on a 2-tier life support response system. Basic life support services provide cardiopulmonary resuscitation (CPR) to stabilize the patient's condition. American Hospital Association (AHA) studies show that CPR must begin immediately for maximum results.[137] CPR must be followed by defibrillation in order to restore heart rhythm and prepare the patient for advanced life support (ALS) services. ALS may include treatments and medications by an on-site emergency medical technician, working interactively with physicians over wireless data and voice communication. The combination of delayed CPR (more than 4 minutes) and delayed advanced life support (more than 12 minutes) is lethal in most cases.

Loudon County, Virginia evaluated its approach to the provision of fire and rescue services. This evaluation reveals that for a nominal 6-minute standard response time, 3 minutes are consumed by relatively fixed elements—dispatch time, turnout time, and setup time—leaving only 3 minutes for travel time. If an average emergency travel speed of 25 mph can be raised to 36 mph with preemption, the effective service radius of a fire and rescue station can be extended from less than 1.25 miles to over 2 miles potentially reducing the need for new stations and/or new equipment.

As part of its 20-year growth plan developed in the mid-1980s, Plano estimated that one fire/rescue and EMS stations would be required for every 5.6 square miles to provide the desired level of service. As the city grew, the response time benefit of EVP has been incorporated into the geographical information systems (GIS)-based planning models the city uses to evaluate fire/rescue and emergency medical service expansion needs. As a result, the city is now serving 7.5 square miles per station instead of the anticipated 5.6 square miles. The benefit to the city is that it is currently operating 10 stations compared to the 13 that had been forecasted, resulting in a capital cost savings for the city of approximately $9 million and an annual operating cost savings of approximately $7.5 million.

[136] American Heart Association

[137] Louisell and Collura, "a simple algorithm to estimate emergency vehicle travel time savings on preemption equipped corridors: a method based on a field operational test," A Paper Presented at the TRB Annual Meeting, January 2005, Washington, D.C.

11.1.7 System Cost

The cost of preemption systems per intersection and per vehicle varies depending on the technology selected, the number of units purchased, and the baseline intersection and vehicle conditions. Across-cutting study reported the following costs based on the survey of three sites.[138]

- Signal Preemption Receiver w/ optional confirmation light: $2,000 to $3,000 with O&M cost of $250 to $500.

- Signal phase selector: $2,000 to $5,000 with no specific O&M cost.

- In-vehicle equipment: $700 to $2,100.

Below are more details about these costs:

- Throughout seven intersections in Fairfax County, the average cost was between $4,000 and $6,000 per intersection (equipping two arterial approaches only). County officials estimated the annual EVP maintenance costs to be between $250 and $500 per intersection per year.

- In Plano, Texas, the traffic engineering department estimates that the cost to install the preemption detection on a new signal at all four approaches is between $5,000 and $8,000.

- The city of St. Paul estimates the cost of equipping a new traffic signal with preemption capability to be approximately $6,000 to $8,000 at all four approaches, provided that the necessary conduits, wiring, and power sources are available.

11.1.8 Assessment

The following can be stated based on the above review:

- IDAS does not consider the effects of preemption on minor movements. The enhancement to the IDAS methodology proposed by McHale and Collura allows the consideration of emergency vehicle preemption on minor movements at the intersection.

- As stated above, IDAS multiplies the reduction in travel time of emergency vehicles to dollar value by 30 times the time value to motorists. This multiplication is arbitrary and does not seem to be satisfactory. In this study, the

[138] "Traffic Signal Preemption for Emergency Vehicles," A Cross-Cutting Study, Produced by the U.S. Department of Transportation, Washington, D.C., January 2006.

dollar values should be assessed considering the impacts described in Section 11.1.7.

- The reduction in the number of emergency vehicle accidents should be calculated based on a reduction of 70 percent in crash rate (number of crashes per response) from the Minnesota Study discussed above.

11.2 Analysis Requirement

The requirements identified in this study for the evaluation of emergency vehicle preemption deployments are listed below.

- The Tool shall allow the user to code the links for which downstream intersections will have emergency vehicles preemption.
- The Tool shall automatically identify the side street links affected by emergency preemption.
- The user shall have the opportunity to input the expected frequency of emergency vehicles at the signalized intersections and default values should be selected for this variable.
- The Tool shall calculate the decrease in travel time on the arterial street using default values that can be changed by the users.
- The Tool shall calculate the increase in delay on cross street due to emergency vehicle (EV) preemption using default values that can be changed by the users.
- The Tool shall calculate the reduction in the number of emergency vehicle crashes.

11.3 Methodology

The methodology used in this Tool is based on the review and requirements presented earlier in this chapter. The method is based on the estimation of the travel time reduction, emergency vehicles crash reduction, and cross street delay increase, that result from project implementation.

Three key elements must be considered when building the evaluation methodology:

- Emergency vehicle travel time reduction: First, the benefits in reducing emergency vehicle travel time will be calculated based on previous findings. The dollar values of the benefits related to what we have called life threatening calls and property fire both come from the reduction in the response time (time required to arrive to the emergency site). The reduction in the response time is a function of the number of intersections with preemption devices that an emergency vehicle must cross in order to arrive at the emergency site.

- The second element is that the safety benefits are related to previous findings about the reduction in crash percentages and are assumed to be proportional to the number of calls served annually by emergency vehicles.
- For the cross street delay evaluation, the proposed methodology will evaluate the total delay on the cross streets based the number of preemptions per hour and the seconds of delay per preemption. Both of these are user inputs. The total delay in this case comes from aggregating the delay for all the crossing links in the improved corridor.

A more detailed description each component is explained below.

11.3.1 Emergency Vehicle Travel Time Reduction

With regard to emergency vehicle travel time reduction, as we mentioned earlier, the response time will be reduced depending on the average number of intersections to be crossed in a typical call. It will be assumed that 15 seconds will be saved per each equipped intersection to be crossed. The user can change this value. Based on the above, it is possible to compute the new response time as follows:

$$t_{withEVP} = t_{withoutEVP} - TTS * n \tag{11-1}$$

where *n* is the number of intersections in a typical call and *TTS* is the travel time savings. A default value of 8 is used for *n* but users can change this value to indicate a station-specific number.

For life threatening calls, the benefits can be computed knowing the reduction in the fatality rate as a function of the reduction in response time. It has been assumed that the probability of death in a life threatening call increases about 10 percent per each minute in late arrival. This pattern applies only between the first minute and the ninth minute of the emergency; afterwards, it is assumed that the probability of survival is 10 percent. Knowing the number of life threatening calls in a year, the benefits can be estimated as:

Life threatening calls benefits = Average life threatening calls × (EVP survival rate- Base survival rate) × (Fatality cost – injury cost)

In the above, EVP refers to emergency vehicle preemption. In terms of property fires, a similar logic applies with the percentage of property losses assumed to depend on the response time, but also to depend on how soon the fire at the site has been detected and the call triggered. For this purpose, the fire classification shown in Table 11-3 is applied.

Table 11-3 Property Loss Percentage by Fire Call Classification[139]

Type of call	Call is originated when the fire is	Average property losses %	α	β
1	Confined to object of origin	0.54	0.04	0.11
2	Confined to part of room of origin	2.95	-0.23	0.66
3	Confined to room of origin	14.40	6.11	1.75
4	Confined to floor of origin	26.30	11.32	3.22
5	Confined to building of origin	48.86	35.35	2.88

The value α represents the percent of increase in property loss as a function of response time in minutes; β represents the constant in the linear function. The percentage of property losses is proportional to the response time in each case, lower in fire calls type 1 than fire calls type 5. The average property losses the previous table corresponds to a response time over the range of 2 to 10 The distribution of the call types can be tailored to local condition, however the default values presented in

Table 11-4 are proposed.[139]

Table 11-4 Fire Type Call Frequency

Type of call	Frequency (%)
1	32
2	19
3	24
4	13
5	12

Knowing the number of total fire property calls in a year, the benefits can be estimated as:

Fire property call benefits = SUM(over all the fire types)[(Total fire calls ×fire call type) (Base fire property loss rate – EVP property loss rate) × Average property cost]

[139] Halpern, J., "Fire Loss Reduction: Fire Detectors vs. Fire Stations", Management Science, Vol. 25, No: 11, Nov. 1979

11.3.2 Crash Benefits

The crash benefits evaluation is fairly straightforward. The rates are obtained on previous experiences with the EVP systems. The values in
Table 11-5 are used as defaults but can be changed by the user.

Table 11-5 EV Crash Rate Used in the Analysis[140]

Crash rate per year per station per intersection without EVP (CEVP)	Crash rate per year per station per intersection with EVP (CNEVP)
0.0287	0.0116

Thus, the benefits due the frequency reduction in the emergency vehicles operation can be computed as:

Crash reduction benefits = Average number of intersections per call in year × (CVEP-CNEVP) × Average Crash Cost

11.3.3 Impact on Cross Streets

Finally, for the cross delay evaluation, the implemented methodology evaluates the total delay on the crossing streets assuming the number of preemptions per hour, the seconds of delay per vehicle per preemption, and the total delay obtained from aggregating the delay for all the crossing links in the improved corridor. Subsequently, the aggregated delay value given the traffic flows on the cross streets can be calculated as follows:

Cross streets cost= SUM(over all the links)[(Preemptions per hour) (Delay per preemption)(Vehicles in the link)(Value of the time]

The default number of delays per vehicle per preemption for the peak and off-peak periods are presented in Table 11-6.

Table 11-6 Default Delay per Vehicle per Preemption

Peak periods cross street delay per vehicle	Off peak periods cross street delay per vehicle
30 seconds	20 seconds

140 "Traffic Signal Preemption for Emergency Vehicles," A Cross-Cutting Study, Produced by the U.S. Department of Transportation, Washington, D.C., January 2006.

11.4 Implementation

The evaluation methodology presented in the previous section is implemented in the FSUTMS/Olympus model, using the script language of the Cube software. As with other ITS applications, the EVP can be selected from a pull-down menu.

11.4.1 Modeling structure

As with other deployments, for Emergency Vehicle Preemption implementation, the modeling structure consists of 3 modules: 1) benefits, 2) costs, and 3) performance. For detailed implementation procedures, the users should refer to the Cube software manual.

11.4.2 Input Interface

Figure 11-2 shows that, as with other ITS deployments, the inputs are organized into five groups (refer to Chapter 5 for details). A description of the parameters that are specific to EVP evaluation is given in this section.

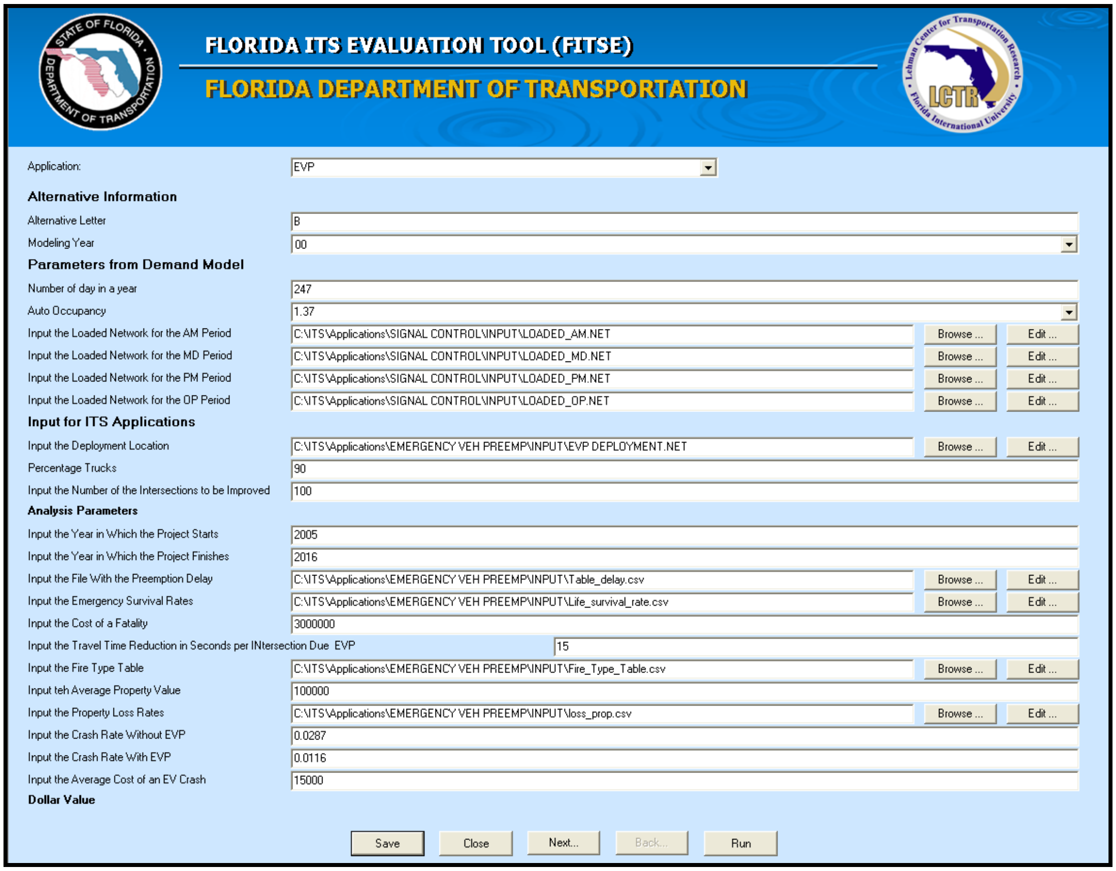
- Location of the ITS deployment: To identify the improved corridor, the attributes PREEMPTED and FLAG are used. The "PREEMPTED" (node attribute equals 1; flagged nodes are displayed as red dots) is added for all the intersections where preemption equipment are to be deployed. The "FLAG" (node attribute equals 1 displayed as green dots) indicates that the link is not a cross street link approaching the affected intersection.
- An additional node-specific attribute, the PPH represents how many signal priority calls are expected per hour for each intersection.
- Another node specific attribute is the "FIRE_STATION" (when set to 1 shows as a blue star) to indicate that a node (usually a new node) is a fire station. The user can add as many stations as needed and also the demographics of emergency calls can be represented for each station by using the following attributes:
    - ◆ LIFE_CALLS is the number of life threatening calls per station per year.
    - ◆ RESP_TIME is the average response time for each station.
    - ◆ AV_INTER is the average number of intersection that an emergency vehicle from a particular station takes to reach the emergency site.
    - ◆ COVERAGE represents the percentage of the calls that get the benefits of preemption since some of the calls may not pass through equipped corridors (the default of this variable is 1.0 but can be changed by the user based on local conditions).
    - ◆ FIRE_CALLS is the number of fire property calls in a year per station.
    - ◆ TOTAL_CALLS corresponds to the total number of calls per station that

requires the dispatch of an emergency vehicle.

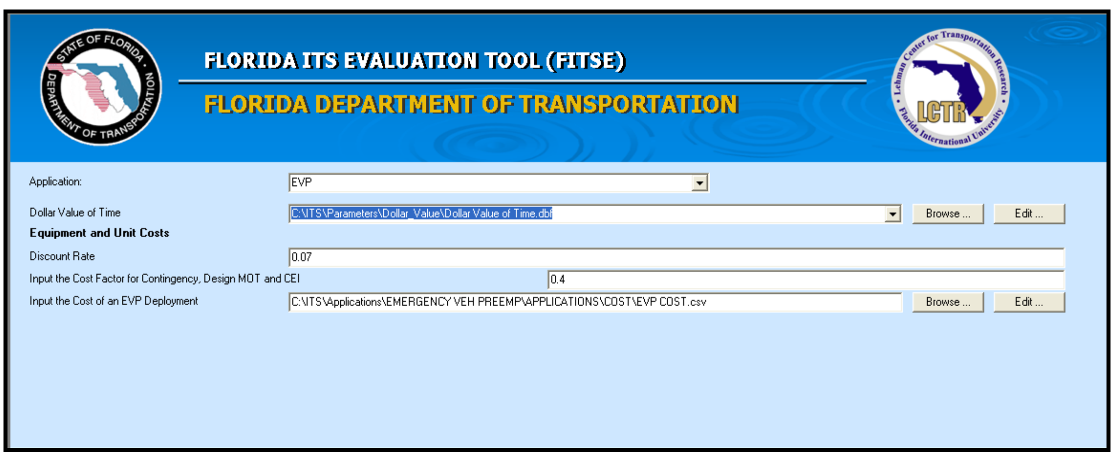
An example is shown in the Figure 11-3.

Other inputs that need to be input by the user in the input interface is

- Number of intersections to be improved: This corresponds to the total number of intersections that the project intends to improve. This number is not used for benefit calculations; instead, is used to compute the total cost of the project.
- Project-year start: Corresponds to the year the program became operational.
- Project-year end: Corresponds to the end of the project evaluation period.
- Emergency survival rates: Defines the chance of survival in a life threatening event, as a function of the time elapsed before receiving assistance (as shown in Figure 11-4).
- Fatality cost: Defines the cost of losing a life (default = $3,000,000).
- Travel time reduction per intersection: Defines the seconds saved per intersection due to the preemption system (default = 15 sec).
- Fire type distribution: Defines the frequency of the different types of fire calls in a region. Figure 11-5 illustrates the corresponding table.
- Average property value: Defines the average property value in dollars in a region (default = 230,000). Property loss rates: Defines the percentage of property loss as a function of the time elapsed between the moment when the call was triggered and the arrival of the firefighters. Figure 11-6 illustrates the corresponding table.
- Crash rate without EVP: Defines the rate of crashes per year per station per call when a preemption system is not utilized (default = 0.0287 per year per station per intersection).
- Crash rate with EVP: Defines the rate of crashes per year per station per call when a preemption system is utilized (default = 0.0116 per year per station per intersection).
- Average cost of a crash: The average cost of having an emergency vehicle crashed en route to the emergency site (default = $15000).



(a) User Input Interface for Emergency Vehicle Preemption



(b) Addition User Input Interface for Emergency Vehicle Preemption

Figure 11-2 User Input Interface for Emergency Vehicle Preemption

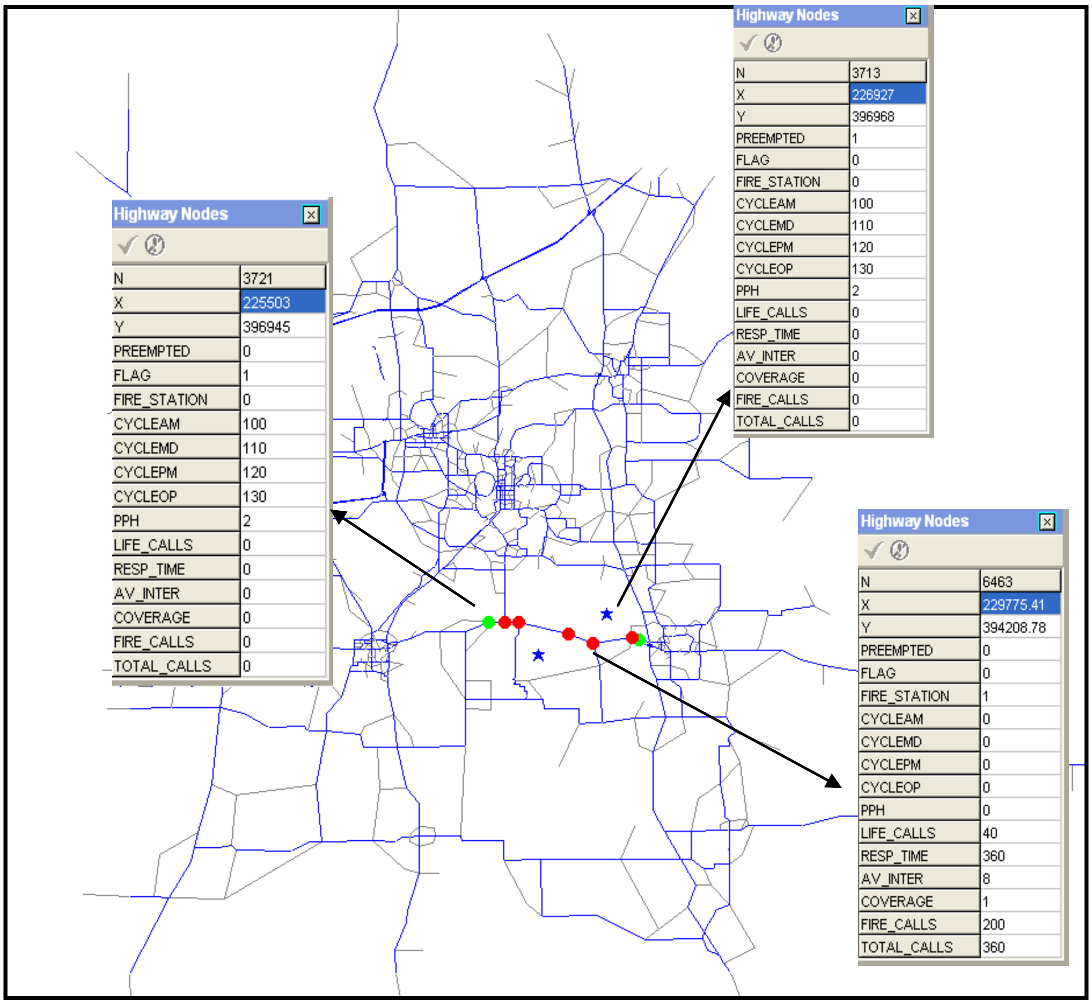


Figure 11-3 Node-Specific EVP Deployment Attributes

	A	B	C
1	60	1	
2	120	0.9	
3	180	0.8	
4	240	0.7	
5	300	0.6	
6	360	0.5	
7	420	0.4	
8	480	0.3	
9	540	0.1	
10	600	0.1	
11			

Figure 11-4 Emergency Survival Rates File/Display

	A	B	C
1	1	0.32	
2	2	0.19	
3	3	0.24	
4	4	0.13	
5	5	0.12	

Figure 11-5 Fire Type Frequency Distribution File

	A	B	C	D	E	F
1	120	0.26	1.09	9.61	17.76	41.11
2	180	0.37	1.75	11.36	20.98	43.99
3	240	0.48	2.41	13.11	24.2	46.87
4	300	0.59	3.07	14.86	27.42	49.75
5	360	0.7	3.73	16.61	30.64	52.63
6	420	0.81	4.39	18.36	33.86	55.51
7	480	0.92	5.05	20.11	37.08	58.39
8	540	1.03	5.71	21.86	40.3	61.27
9	600	1.14	6.37	23.61	43.52	64.15

Figure 11-6 Loss Property Rates File

11.4.3 Output Interface

As indicated in Figure 11-7 to Figure 11-9, three standard output files are generated for EVP: 1) performance summary, 2) benefits summary, and 3) benefits and costs summary. These three files are organized under the output category in the data window.

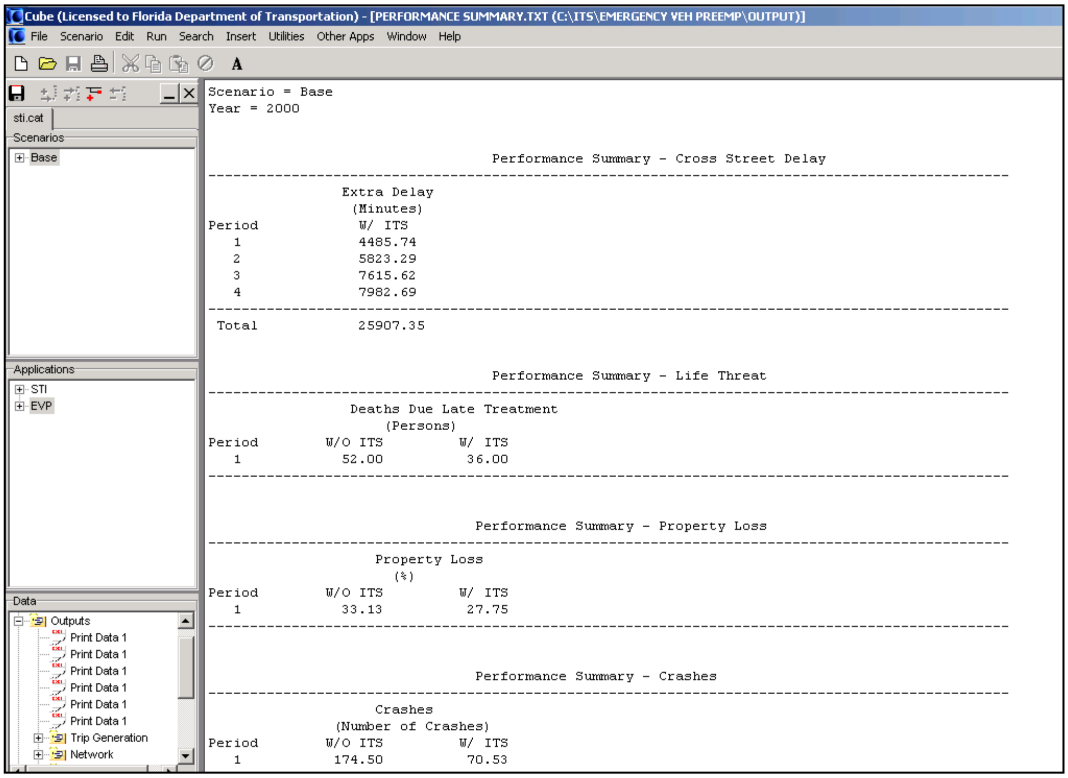


Figure 11-7 Performance Summary Output File for EVP

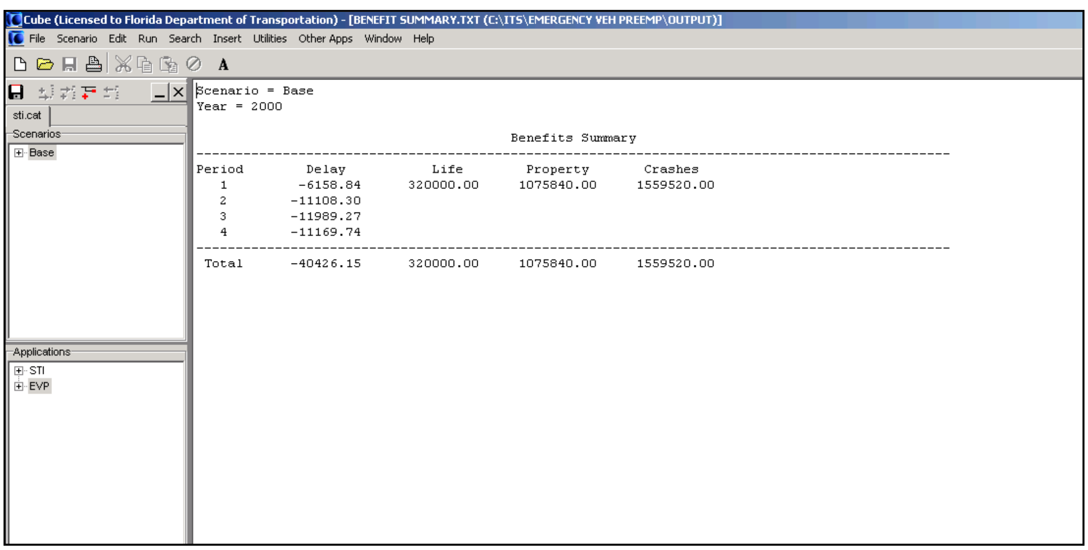


Figure 11-8 Benefit Summary Output File for EVP

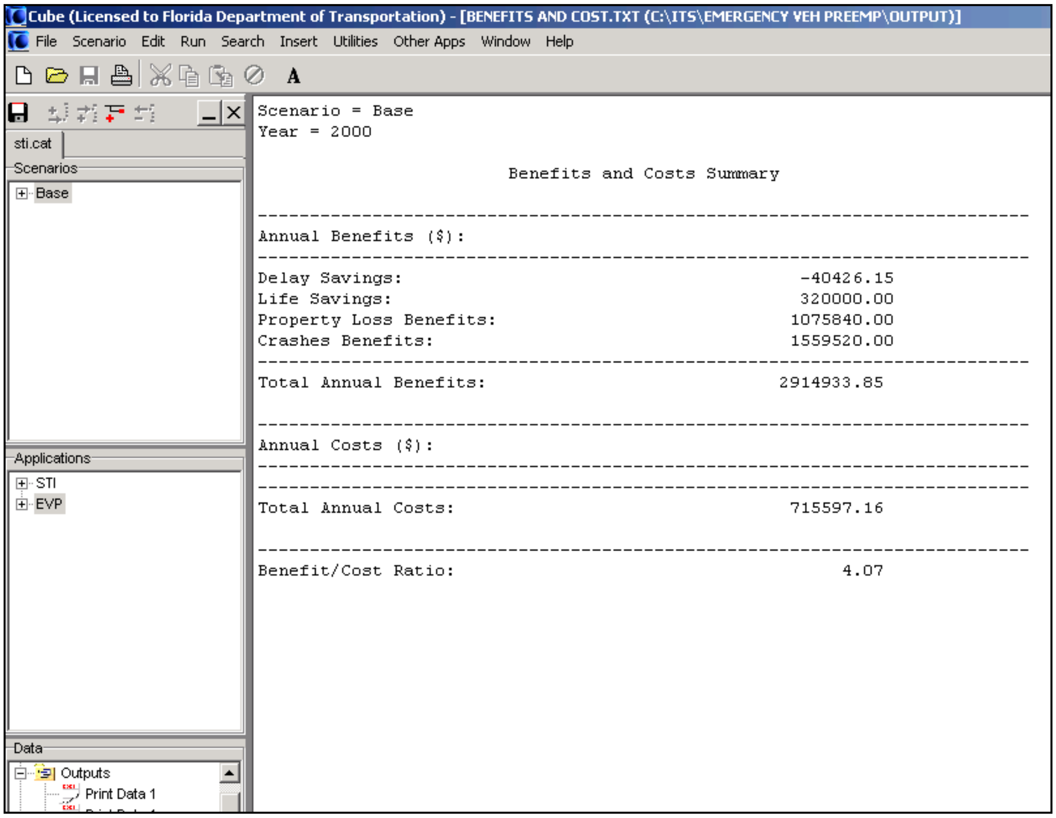


Figure 11-9 Benefits and Costs Summary Output File for EVP

12 Transit Vehicle Signal Priority

Transit Signal Priority (TSP) is an operational strategy that facilitates the movement of in-service transit vehicles through traffic signal controlled intersections. This priority is different from the preemption used for emergency vehicles discussed in the previous section. While they may utilize similar equipment, signal priority modifies the normal signal operation process to better accommodate transit vehicles, while preemption interrupts the normal process. Objectives of transit signal priority include improved schedule adherence, improved transit efficiency, contribution to enhanced transit information, and increased road network efficiency.

TSP can be implemented in a variety of ways including passive priority, early green (red truncation), green extension, actuated transit phase, phase insertion, phase rotation, and adaptive/real-time control.

12.1 Previous Approaches

This section presents a review of tools and studies that address the evaluation of transit vehicle priority.

12.1.1 IDAS Methodology

With the deployment of Transit Vehicle Signal Priority, IDAS assumes that the priority link speed increases, which reduces travel time, crash frequency, pollutant emissions, and fuel consumption. In IDAS, the decrease in the corresponding cross-link speed is ignored. The ratio of ITS option (bus priority) travel time to control alternative travel time of transit vehicles for each origin-destination pair is calculated and applied as an adjustment factor to derive the new transit in-vehicle travel time. IDAS uses an increase of 13 percent in link speed as the default value for transit vehicle signal priority. The mode choice analysis is then conducted by using the new travel time. A final trip assignment is performed for the benefit and cost analysis.

As stated above, IDAS uses an increase of 13 percent in link speed as the default value for transit vehicle signal priority. This was based on previous evaluation studies that found the benefits to range between 1.4 percent and 42 percent. The evaluation studies were for systems implemented in Ann Arbor, Atlanta, Australia, Chicago, China, Dallas, Dekalb County (GA), England, France, Italy, Japan, Los Angeles, Minneapolis, Oakland, Berkeley (CA), Portland (OR), Seattle, and Washington D.C.

12.1.2 Virginia Tech Service Reliability and Efficiency Assessment

An assessment conducted by Virginia Tech[141] identified specific performance measures for use as part of an evaluation framework of transit signal priority. This framework was applied to a corridor along Columbia Pike in Arlington, Virginia. The INTEGRATION simulation tool was used to model the test corridor. The identified measures of effectiveness included bus schedule reliability, bus efficiency, and bus delay measures.

The study results indicate that bus service reliability improved 3.2 percent, bus efficiency improved 0.9 percent, and non-transit delay in the overall corridor increased approximately 1.0 percent per vehicle or 0.6 percent per person.

12.1.3 North Dakota Transit Priority Simulation Study

A North Dakota[142] study used the VISSIM simulation tool to examine the impact of two TSP strategies: early green and extended green on transit operations on a case study network. The measures of effectiveness used in the study were side street person-delay, network person-delay, bus travel time, and bus delay.

The results indicated that the travel time savings ranged from 12.4 percent to 14.2 percent for all midday period scenarios. The afternoon period early green scenarios resulted in a travel time savings of 10.6 percent and 9.5 percent for 15-minute and 30-minute headways, respectively. Similarly, the afternoon period extended green strategy resulted in a 2.4 percent reduction (statistically insignificant change for the 15-minute headway). In terms of vehicle-hour of delay, the cross street delay increased by 16-24 percent for the 15 minute headway scenario and 16-18 percent for the 30 minute headway scenario for the afternoon peak. For the midday period, the increase in delay was small in both scenarios (0.15-0.39 percent).

12.1.4 King County Demonstration Project, Washington

The King County Demonstration Project involved evaluating TSP for buses equipped with automatic vehicle identification (AVI) tags. Three local jurisdictions developed specific TSP strategies tailored to their own needs, mainly employing minor variations of the green extension and early green/red truncation strategies. Dale et

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[141] Chang, J., "Evaluation of Service Reliability Impacts on Traffic Signal Priority Strategies for Bus Transit," Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University, Falls Church, VA, 2002.

[142] Ova, K. and A. Smadi, "Evaluation of Transit Signal Priority Strategies for Small-Medium Cities," The Upper Great Plains Transportation Institute, Fargo, North Dakota, 2001.

al.[143] performed the field evaluations of the TSP. Data were collected from three TSP intersections and extrapolated for the analysis. The analysis included both AM peak and midday-peak periods. Several MOEs were gathered for transit and non-transit traffic. Impacts on non-transit traffic delay (seconds/vehicle) ranged from a 13 percent reduction in the AM to a 9 percent increase for the midday period. Intersection bus delay was reduced by an average of 34 percent for the AM peak period and 24 percent for the midday-peak period. The estimated travel time saving for buses was 8 percent through the corridor. Finally, the average person-delay, which provides a comprehensive measurement of delay when comparing different modes, ranged from a 13 percent reduction for the AM period to an 8 percent increase for the midday-peak period.

12.1.5 Assessment

Based on the results presented in this section, it can be estimated that bus priority can result in the following impacts:

- Improves travel time on the corridor by 10-12 percent. The reduction in bus delay per intersection can range from 15 to 30 percent depending on the red time that the bus gets, which is a function of the congestion level in the system for the period under investigation.
- For cross street transit, the delay at individual intersections increases by 6 percent each time transit vehicles pass through during the peak periods and by 0 percent during the off-peak periods.

12.2 Analysis Requirements

Below are the requirements identified for the evaluation of transit signal priority.

- The Tool shall allow the user to code the links for which downstream intersections will have bus priority.
- The Tool shall allow the user to identify side street links affected by bus priority.
- The Tool shall be able to calculate the frequency of preemption at signalized intersections based on the transit lines passing through the nodes.
- The Tool shall calculate the decrease in travel time of the bus the arterial street using default values that the user can change.
- The Tool shall calculate the benefit to the network by performing mode choice analysis based on the new travel time followed by trip assignment.
    - Mode choice analysis and traffic assignment shall be performed using the regionally calibrated FSUTMS models.

[143] Dale, J., J. Atherley, J. Ronald, T. Bauer and L. Madsen, “A Transit Signal Priority Impact Assessment Methodology - Greater Reliance on Simulation,” Transportation Research Board, 78th Annual Meeting Proceedings, Washington, D.C., January 2000.

- The Tool shall calculate the increase in delay on cross street due to bus priority, using default values that the user can change.

12.3 Methodology

The methodology used in this Tool is based on the review and requirements, as presented earlier in this chapter. The method is based on the estimation of the transit vehicle travel time reduction and the increase in cross street delay. Figure 12-1 presents an overview of the used methodology.

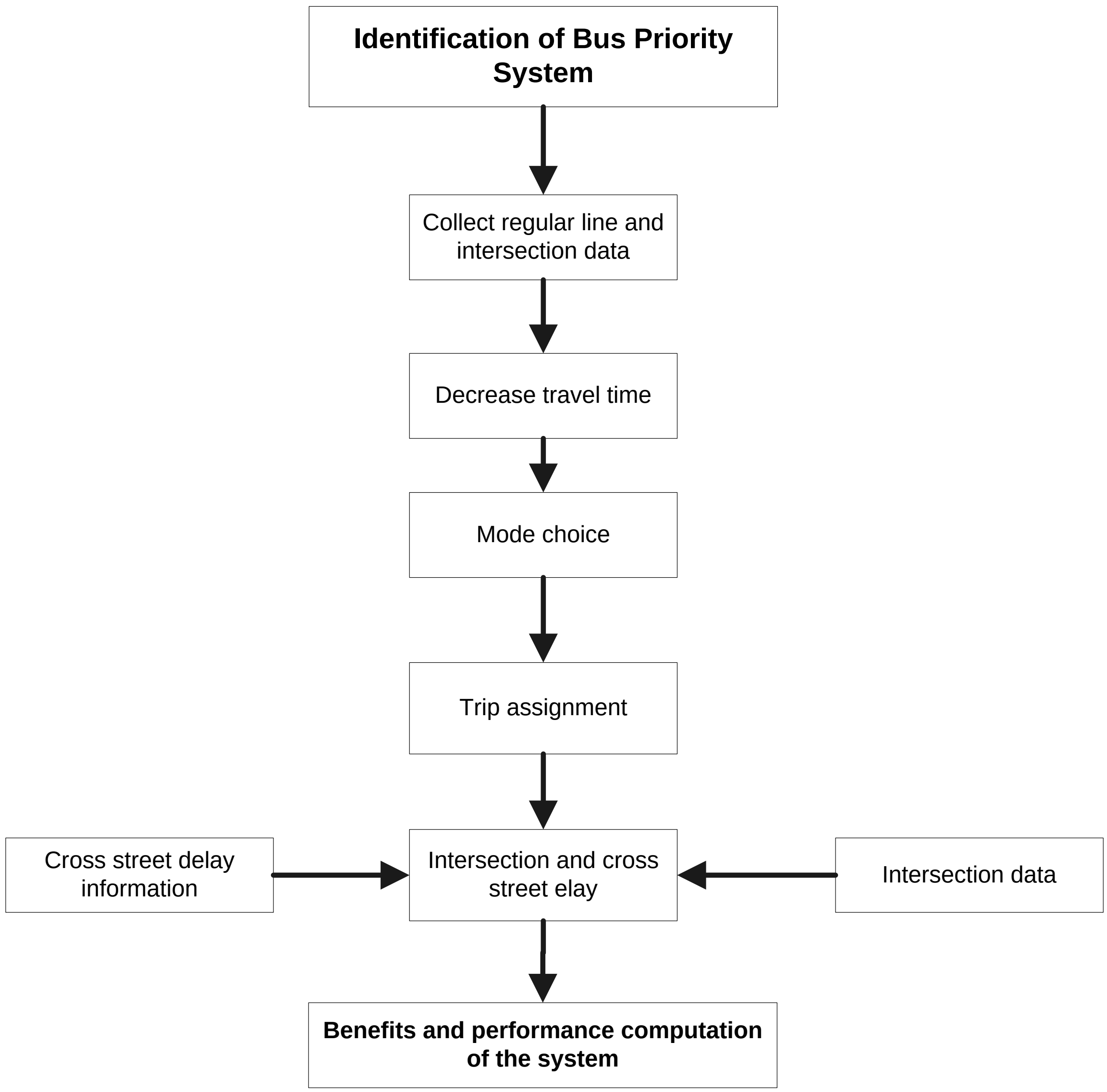


Figure 12-1 Bus Priority Implementation Flow Chart

Based on user input, the affected links, intersections and the transit lines with bus priority are identified. The transit line information and network geometry are extracted from the demand model. Based on the above information, the bus priority implementation is defined as part of the network. The travel times of the affected transit system lines are decreased based on a travel time decrease percentage default value for this effectiveness percentage is provided, as described in the next section. However, the user can change this value. After the transit travel time is reduced, the mode choice and assignment steps of the calibrated FSUTMS demand models are rerun with the new travel times and the new demands and measures of effectiveness are calculated.

After the assignment step, an increase in cross street delay is added to account for the additional delay incurred by cross street movements due to preemption. The cross street delay is calculated based on the estimated number of the bus priority calls, cross street traffic volumes, transit system on time performance (input by the user), and intersection data. The remaining discussion in this section discusses how cross street delays are calculated.

The probability of priority calls at an intersection depends on number of transit vehicles that approach the intersection and the directional distribution of the transit vehicles. Directional distribution is important since two transit vehicles from opposing directions can place a call for signal priority at the same time thus reducing the number of calls. In Figure 12-2, A and B indicate two transit vehicles approaching an intersection from opposite directions.

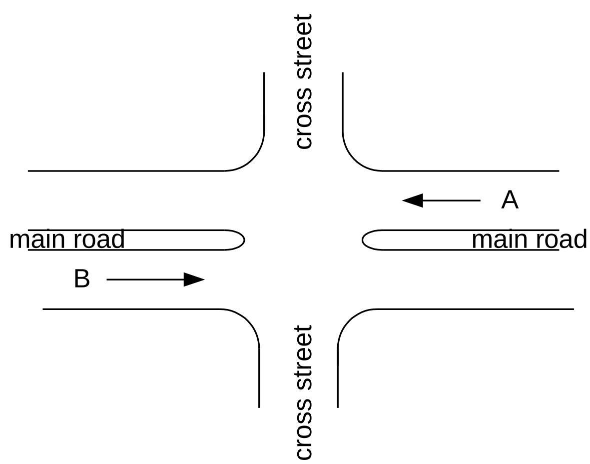


Figure 12-2 Typical 4 leg Intersection with Bus Priority

Below is a discussion of how the number of calls at an intersection is calculated.

The number of the cycles (N_C) in hour at the intersection is:

$$N\_C = \frac{3600}{C} \quad (12\text{-}1)$$

where:

N = Number of Cycles
C = Cycle Length (sec)

Transit system on time performance is also considered. The number of transit vehicles (OBa and OBb) that are not 'on time' are computed as follows:

$$OBa = \frac{(100 - Op) * Bat}{100} \quad (12\text{-}2)$$

$$OBb = \frac{(100 - Op) * Bbt}{100} \quad (12\text{-}3)$$

where:

Bat = number of buses direction A
Bbt = number of buses direction B
Op = On time performance of transit system (%)

To consider the directional distribution of transit vehicles, the number of bus priority call is calculated as shown below.

If OBa<Nc and OBb<Nc

$$Pn = \frac{(NC - OBa)}{NC} * \frac{(NC - OBb)}{NC} \quad (12\text{-}4)$$

$$Pb = 1 - Pn$$

If OBa≥NC and OBb≥NC

$$Pn=0$$

$$Pp = 1$$

where:

Pn = Probabilityof no preemption
Pp = Probability of preemption

$$N\_P = (OBa + OBb) * P_p \quad (12\text{-}5)$$

The cross street delay can then be calculated due to the implementation of bus priority:

$$BP\_D = Cd * C_{D\_P} * V * \frac{N\_P}{N\_C} \qquad (12\text{-}6)$$

Where:
BP_D: Bus priority delay
Cd : Delay per vehicle = (C-G)/2
C_{D_P} : Bus priority delay increase (default = 20% percent)
G: Cross street green time (seconds)
V: Cross street link volume
N_P: Number of preemption (if N_P≥5 → N_P=5)

12.4 Implementation

The evaluation methodology presented in the previous section is implemented in the FSUTMS/Olympus model, using the script language of the Cube software. As with other ITS applications, the transit priority can be selected from a pull-down menu.

12.4.1 Modeling Structure

For transit signal priority systems, the modeling structure consists of matrix and highway network preparation, transit system path, skim tables preparation, mode choice, assignment, performance summary, cost, and benefits and cost modules, as shown in Figure 12-3. For detailed implementation procedures, users should refer to the catalog in the Cube software.

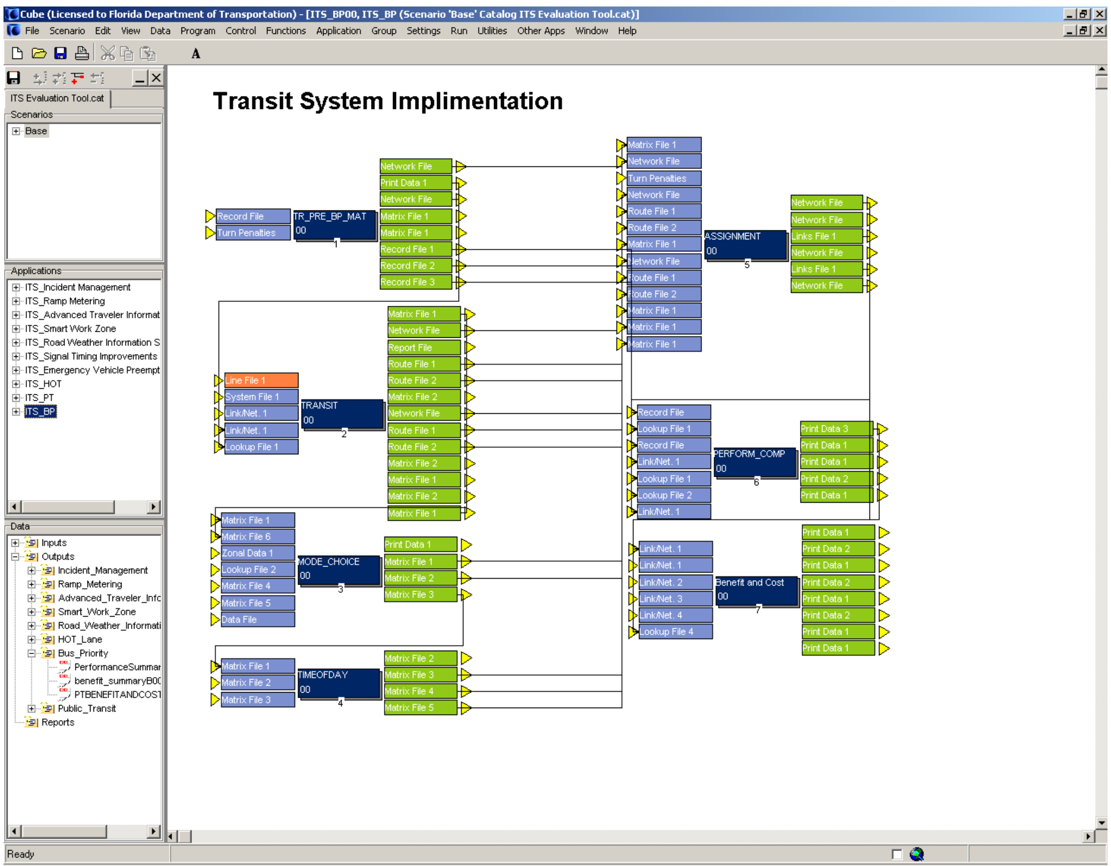


Figure 12-3 Modeling Structure of Bus Priority System

12.4.2 Input Interface

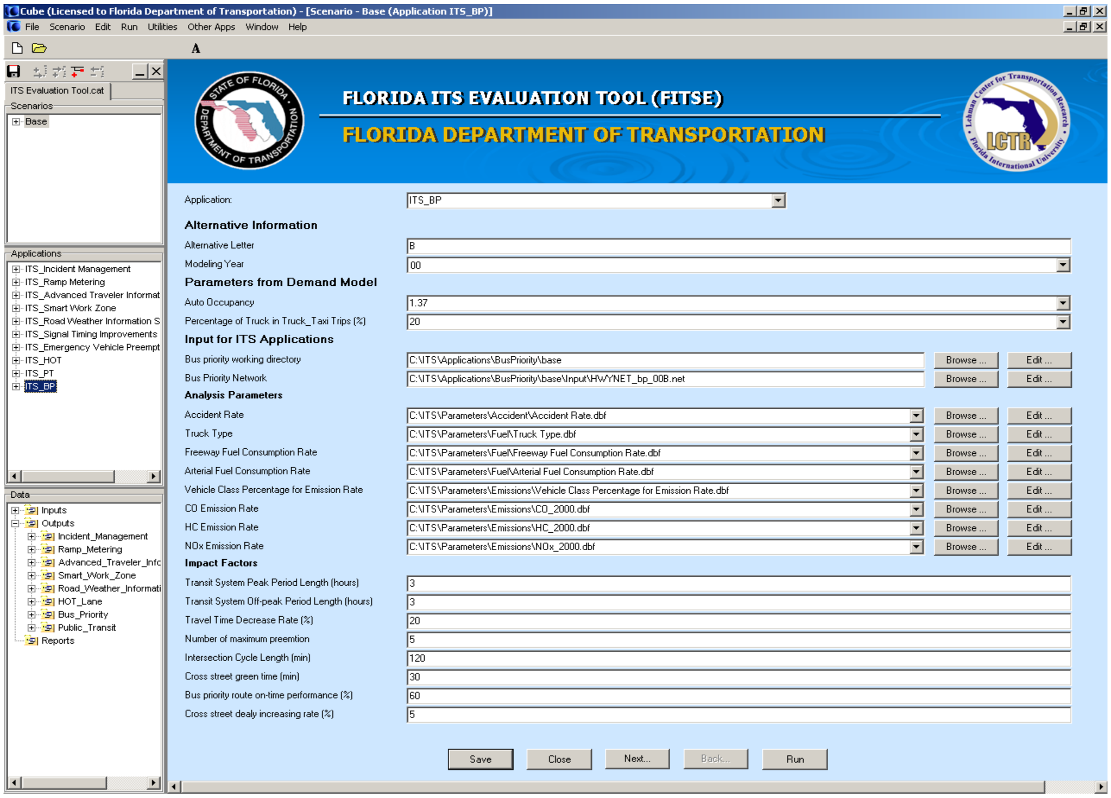
Figure 12-4 shows that, as with other ITS deployments, the inputs are organized into five groups (refer to Chapter 5 for details). A description of the parameters that are specific to EVP evaluation is given in this section.

- Location of bus priority network: for this purpose, the user has to define the main road with bus priority and cross street links for the implementation. A new attribute is added to the link named “BUSPRIORITY” as shown in Figure 12-5 and Figure 12-6. This attribute takes the following values:
  - “0” for links not affected by bus priority.
  - “1” for bus priority links (main road).
  - “2” for cross street links on intersections with main street having bus priority.
  - “3” for a link that is both a bus priority link and also a cross street links.

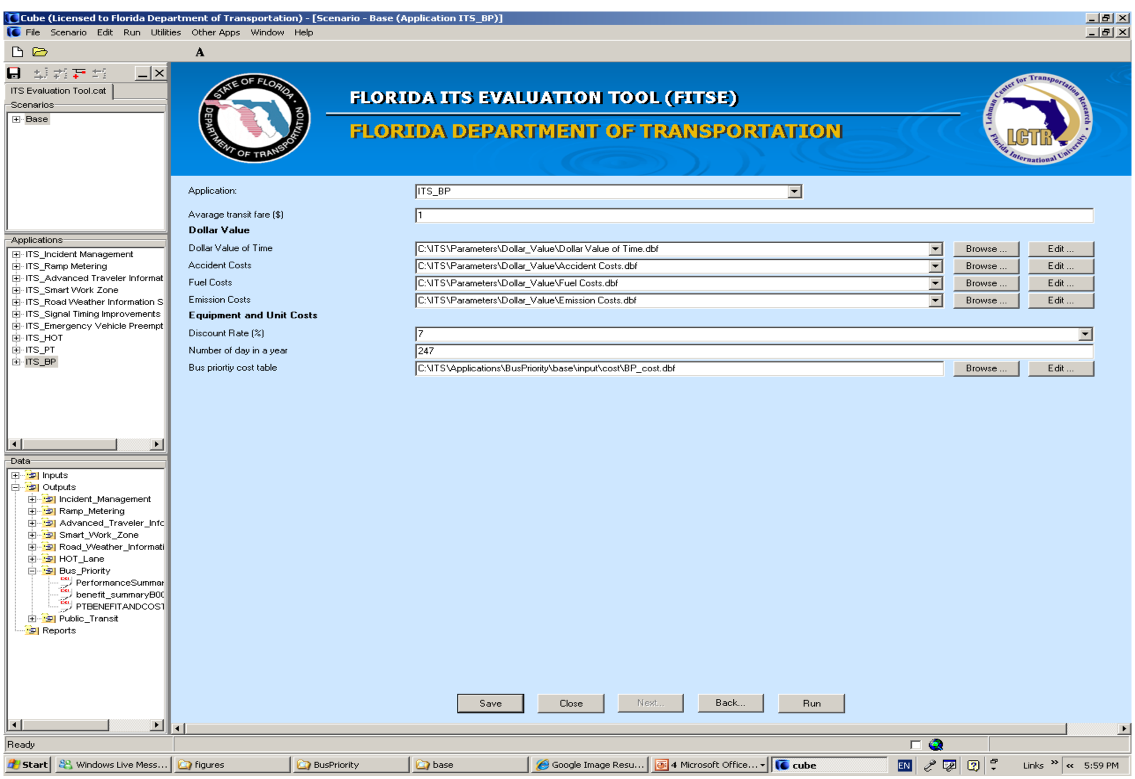
- Impact factors:
  - Transit system peak period length (default = 3 hours).
  - Transit system off-peak period length (default = 3 hours).
  - Travel time decrease rate (default = 20 percent).
  - Maximum number priority calls at each intersection that is considered in the calculation (default = 5).
  - Intersection cycle length (default = 120 sec).
  - Average cross street green time (default = 30 sec.).
  - Bus priority route on-time performance: percentage of vehicles that are meeting their schedule at any given time (default = 60 percent).
  - Average transit fare (default = $1).

12.4.3 Output Interface

As indicated in Figures 12-7 to 12-9, three standard output files are generated for EVP: 1) performance summary, 2) benefits summary, and 3) benefits and costs summary. These three files are organized under the output category in the data window.



(a)



(b)

Figure 12-4 User Input Interface for Transit Signal Priority

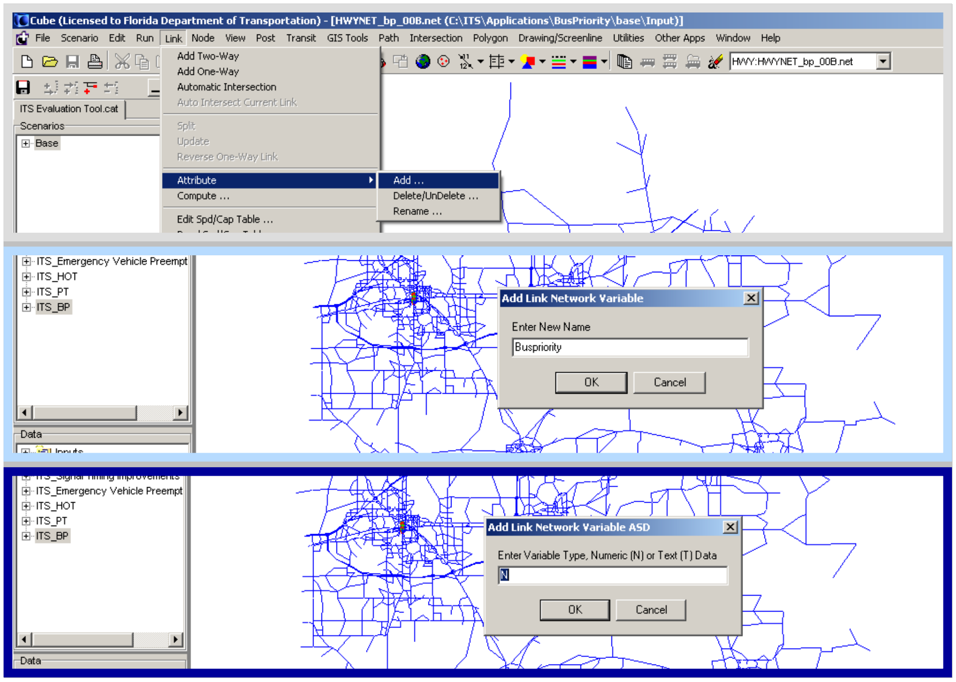


Figure 12-5 Defining the "BUSPRIORITY" Attribute

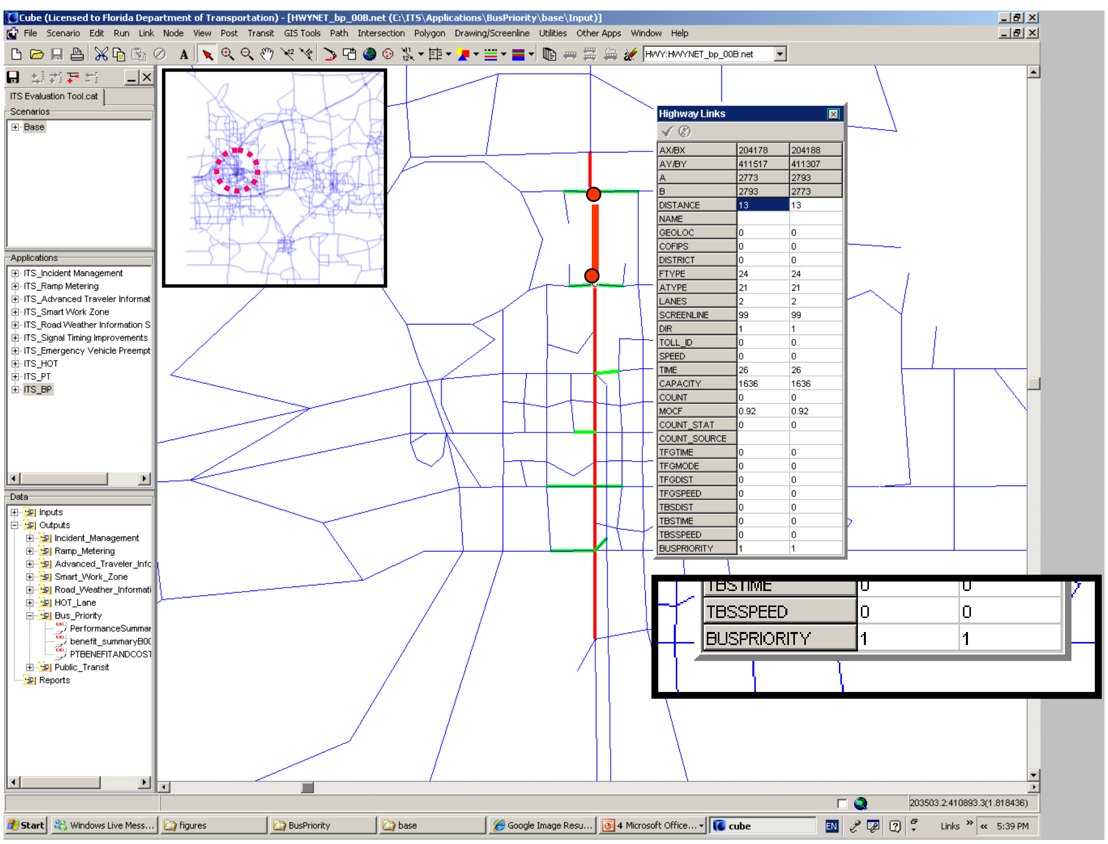
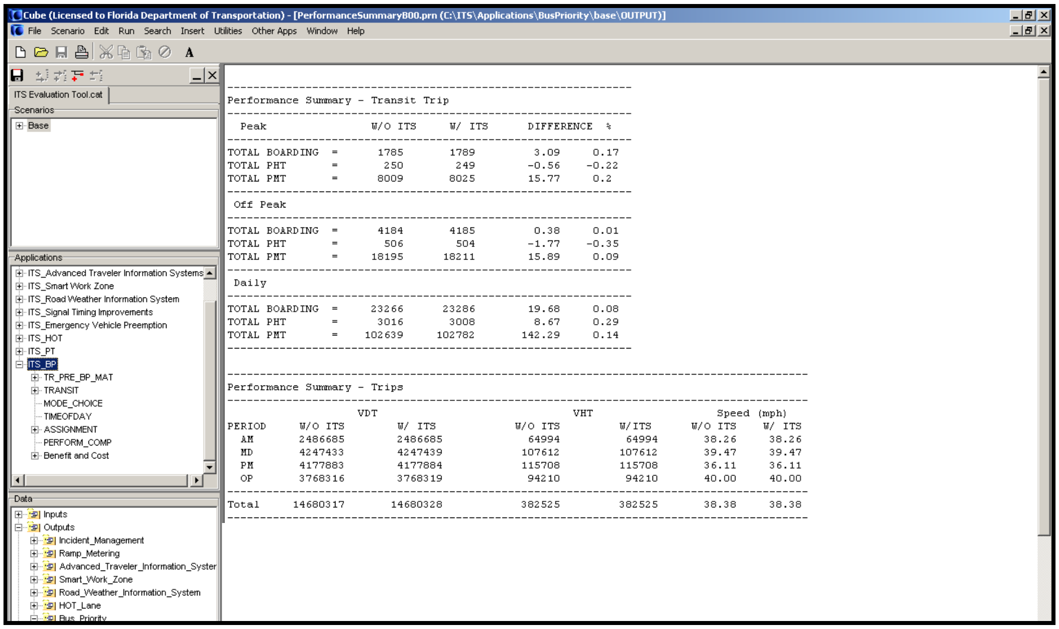
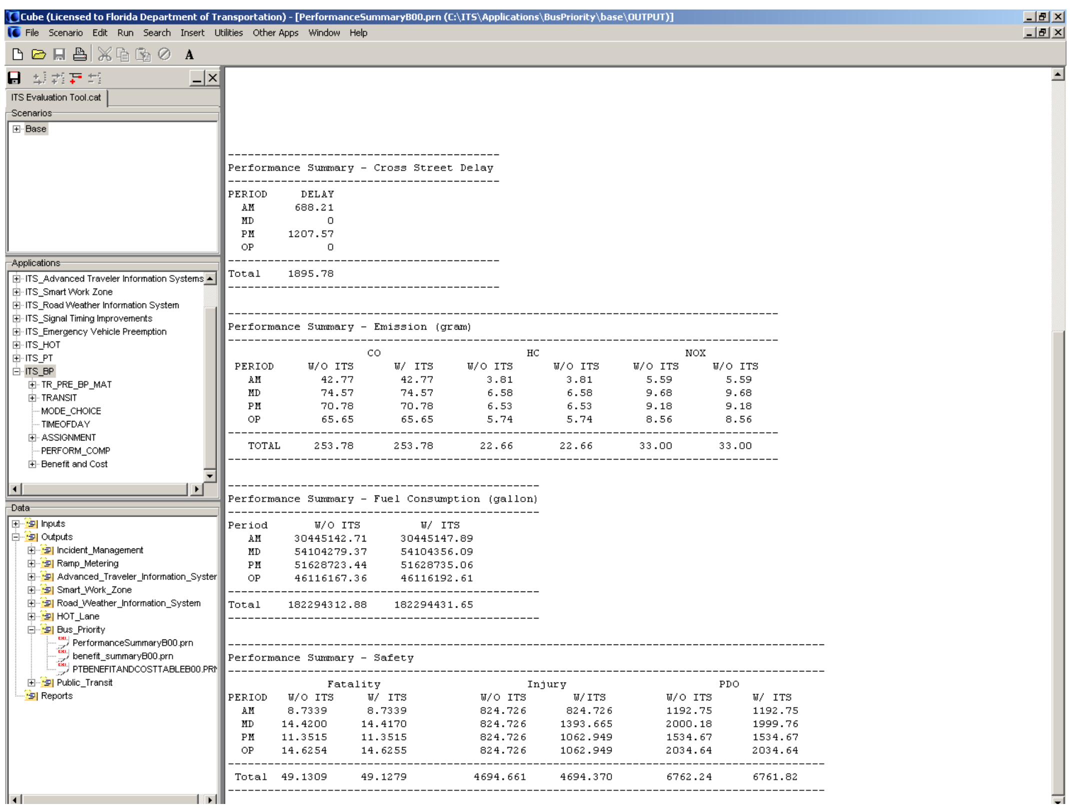


Figure 12-6 Bus Priority Coded Network

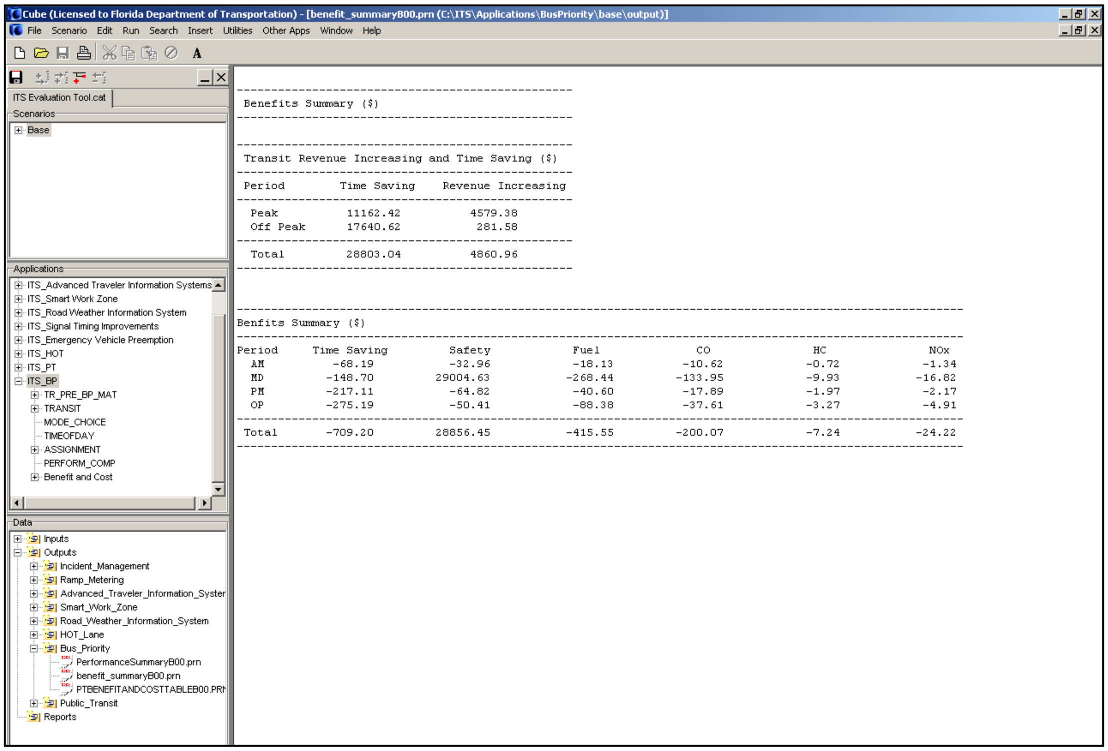


(a)



(b)

Figure 12-7 Performance Summary Output File for Transit Priority



Benefits Summary ($)

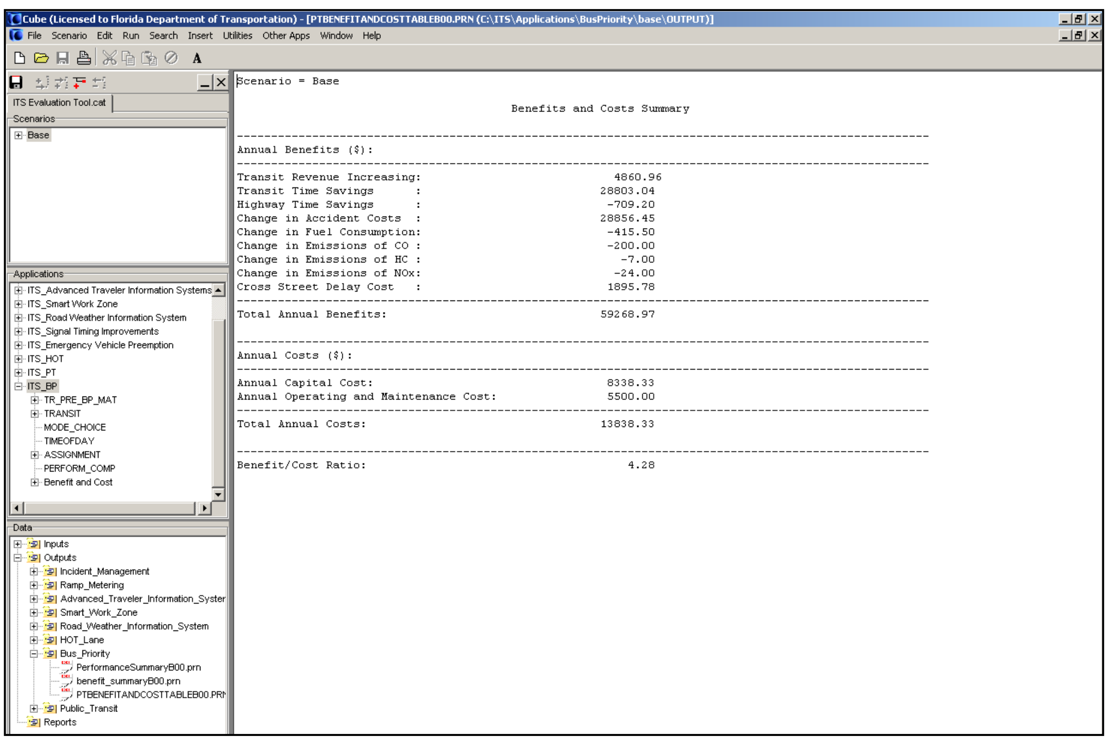
Transit Revenue Increasing and Time Saving ($)

Period	Time Saving	Revenue Increasing
Peak	11162.42	4579.38
Off Peak	17640.62	281.58
Total	28803.04	4860.96

Benfits Summary ($)

Period	Time Saving	Safety	Fuel	CO	HC	NOx
AM	-68.19	-32.96	-18.13	-10.62	-0.72	-1.34
MD	-148.70	29004.63	-268.44	-133.95	-9.93	-16.82
PM	-217.11	-64.82	-40.60	-17.89	-1.97	-2.17
OP	-275.19	-50.41	-88.38	-37.61	-3.27	-4.91
Total	-709.20	28856.45	-415.55	-200.07	-7.24	-24.22

Figure 12-8 Benefit Summary Output File for Transit Priority



Scenario = Base

Benefits and Costs Summary

Annual Benefits ($):	
Transit Revenue Increasing:	4860.96
Transit Time Savings :	28803.04
Highway Time Savings :	-709.20
Change in Accident Costs :	28856.45
Change in Fuel Consumption:	-415.50
Change in Emissions of CO :	-200.00
Change in Emissions of HC :	-7.00
Change in Emissions of NOx:	-24.00
Cross Street Delay Cost :	1895.78
Total Annual Benefits:	59268.97

Annual Costs ($):	
Annual Capital Cost:	8338.33
Annual Operating and Maintenance Cost:	5500.00
Total Annual Costs:	13838.33

Benefit/Cost Ratio: 4.28

Figure 12-9 Benefit and Cost Summary Output File for Transit Priority

13 Signal Control

Improvements to signal control systems are among the most effective ITS improvements. These improvements range from simply retiming the signals at relatively low cost to the installation of state-of-the-art regional signal control systems that costs multi-million dollars.

13.1 Previous Approaches to Evaluation

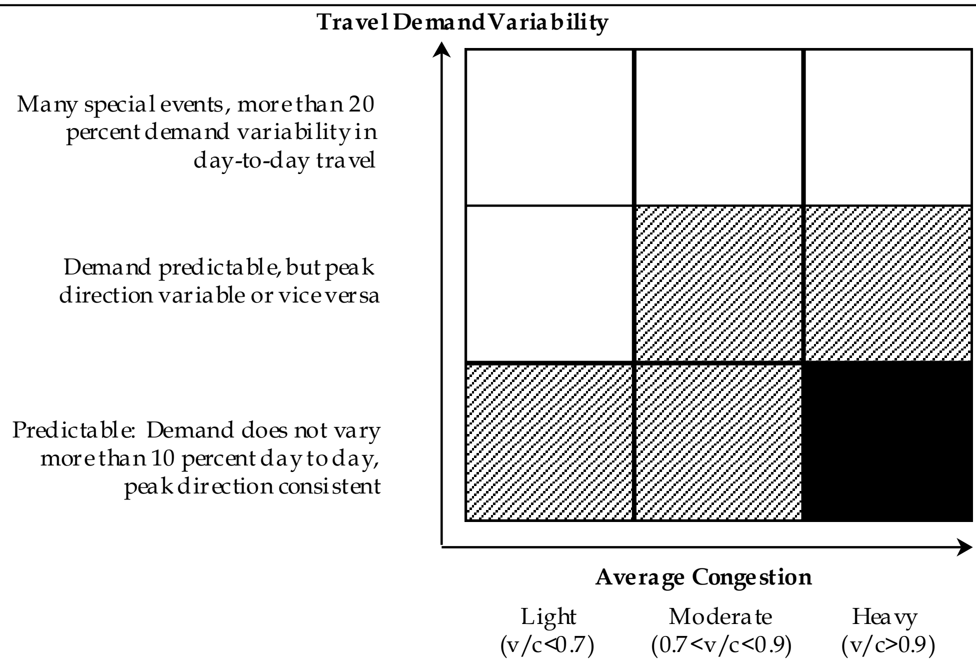
This section presents a review of tools and studies that address the evaluation of improvements to signal control systems.

13.1.1 IDAS Methodology

In IDAS three types of signal control are studied: 1) Isolated Traffic Actuated Signals, 2) Preset or Actuated Corridor Traffic Signal Coordination, and 3) Central Control Traffic Signal Coordination. Below is a description of how IDAS calculates the benefits of signal control systems:

- Isolated Traffic Actuated Signals: IDAS assumes that the deployment of signals and periodic retiming of the signals will increase the signal throughputs. Impact is classified into nine categories by travel demand variability (percentage day-to-day demand variation) and average congestion (v/c ratio). For each category, the percentage increase in capacity is assumed to depend on the time interval between signal-timing modifications. Based on the input of travel demand variability, average congestion range, and time interval between signal-timing modifications, the increase in capacity, which ranges between 8 percent and 25 percent, is determined using look-up tables. After this increased capacity is applied to the links with Isolated Traffic Actuated Signals, the trip assignment procedure for the scenario with signal improvement is run to obtain the changes in VMT, VHT, travel time, and delays. Based on the changes in these measures, the reduction in number of accidents (including fatalities, injuries, and property damage only), pollutant emissions, and fuel consumption are obtained and converted to monetary values. Figure 13-1 shows the parameters IDAS uses in calculating the isolated traffic actuated signal impacts.
- Preset or Actuated Corridor Traffic Signal Coordination: The IDAS evaluation of this deployment is similar to the Isolated Traffic Actuated Signals with different percentage increases in the operational capacity. For coordinated links, the capacities are assumed to increase by 14 to 20 percent, while the capacities for cross-street links are assumed to reduce by this same amount. IDAS runs the trip assignment, mode choice and temporal choice to calculate the demands for this option.
- Central Control Signal Coordination: The approach used in evaluating this type of deployment is similar to the approaches used in the other two approaches. The

assumed increase in link capacities for this type of deployment ranges from 6 to 18 percent. IDAS runs the trip assignment, mode choice and temporal choice for the ITS option in order to calculate demand.



High Impact
Increase Capacity by: Low Range = 13 percent, High Range = 25 percent

Medium Impact
Increase Capacity by: Low Range = 11 percent, High Range = 19 percent

Low Impact
Increase Capacity by: Low Range = 8 percent, High Range = 13 percent

Time Interval between Signal Timing Plan Modifications: See chart, select range, and modify impact by appropriate factor.

High End of Range	Higher Impact	Average Impact	Lower Impact	Low End of Range
> 8 Years HR	> 4 Years (3HR+LR)/4	>2 Years (HR+LR)/2	Updated Annually (3LR+HR)/4	Updated Frequently LR

HR = High range of the selected impact
LR= Low range of the selected impact

Figure 13-1 Benefit Calculation Parameters Used by IDAS for Isolated Actuated Signal Impacts

13.1.2 ITSOAM Methodology

ITSOAM calculates the benefits for only one type of signal control: adaptive signal control. Travel time before the deployment of adaptive traffic signal control systems are calculated based on the user input of weekday VMT and average traffic speed on arterials. The vehicle hours traveled after the deployment of adaptive control is estimated based on an assumed increase in average traffic speed. The difference between the vehicle hours traveled before and after deployment is calculated to represent the travel time savings. The safety benefits are considered by using a default value of 25 percent reduction in weekday accidents. The increased speed due to the adaptive traffic signal control systems is also used to determine the levels of pollutant emissions and fuel consumption after the deployment, which in turn are compared to the values before the deployment to give the annual benefits.

13.1.3 Evaluation of Sarasota-Manatee County Signal System

SCRITS has a “Signal” spreadsheet to calculate the benefits and costs of signal control improvements. The spreadsheet does not specify the type of improvement but allows the user to modify the percentage reductions in travel time, stops, and crashes. Thus, it can be used to evaluate generic types of signal control improvements and the user can input the percentages of improvements in various performance measures that are specific to the evaluated improvement type. To estimate the benefits of ITS improvements, these percentages are then multiplied by the annual VHT, estimated number of accidents, fuel consumption, and emissions for the no improvement scenarios.

Hadi and Hamad[144] discussed the use of SCRITS for the benefit-cost analyses of signal system alternatives for a large urban area (the Sarasota-Manatee County region). This region included 10 municipalities within the Sarasota-Manatee County region in Florida and encompasses 520 fully operational signals. The study evaluated two alternatives:

- Alternative 1: Maintaining the status quo and making small improvements to a fully operational system. This includes maintaining and replacing controllers and detectors and retiming signals. The benefit of this alternative was assumed to be a 6 percent reduction in travel time and a 10 percent reduction in accidents.
- Alternative 2: Upgrading the system to a state-of-the-art two-level distributed system, managed from a new regional traffic control center with system wide

[144] Hadi, M.A. and A. Hamad, “SCRITS Benefit-Cost Analyses for Signal Systems,” The 2004 ITE Annual Meeting, Orlando, Florida, August 2004.

traffic surveillance capabilities. The benefit of this alternative was assumed to be 18 percent reduction in travel time and a 25 percent reduction in accidents.

13.1.4 University of California at Berkeley Study

Skabardonis[145] presented the findings from the analysis of the impacts of signal control improvements based on a large number of real-world implemented projects. Three major types of signal control improvements were analyzed: 1) optimization of existing signal timing plans, 2) signal coordination, and 3) traffic responsive control. The analysis was based on the results of actual real-world projects undertaken as part of the California's Fuel Efficient Traffic Signal Management (FETSIM) Program. The effectiveness of traffic responsive control was discussed based on real-world data from the Los Angeles Advanced Traffic Control and Surveillance System (ATSAC).

Based on macroscopic simulation modeling (using the TRANSYT macroscopic simulation model), signal-timing optimization of coordinated signal systems was shown to produce an average of 7.7 percent drop in travel time, 13.8 percent reduction in delays, 12.5 percent reduction in stops, and 7.8 percent decline in fuel use. These average improvements were based on 163 projects (49 percent) of the total 334 projects in the FETSIM program and 6701 signalized intersections (55 percent of the total retimed signals). Because the TRANSYT model often overestimates savings at intersections when oversaturation occurs, such links were eliminated when calculating the average improvements for each project. Field studies were performed before and after the implementation of the optimized timing plans to measure the improvements in traffic flow using floating car studies. The average measured savings for coordinated systems were 7.4 percent reduction in travel time, 16.5 percent reduction in delay, and 17 percent reduction in stops. These measured benefits are generally in agreement with the TRANSYT model estimates.

Figure 13-2 shows the distribution of percent savings in delay and stops. The level of improvements in traffic performance varied considerably among the retimed projects. Some agencies found little or no improvement, and others reported gains of over 30 percent in delay and stops, and 20 percent reduction in fuel consumption. The improvements depend on factors such as quality of existing timing plans, network configuration (larger savings were realized on arterials than on grid networks), traffic patterns (larger savings were obtained on high volume systems with predominant through movements, although marginal savings were found on systems with several congested intersections that are in need of capacity improvements), and signal equipment (higher benefits were obtained on systems with actuated signal).

[145] Skabardonis, A., "ITS Benefits: The Case of Traffic Signal Control Systems," Presented at the Transportation Research Board 80th Annual Meeting, Washington, D.C., January, 2001.

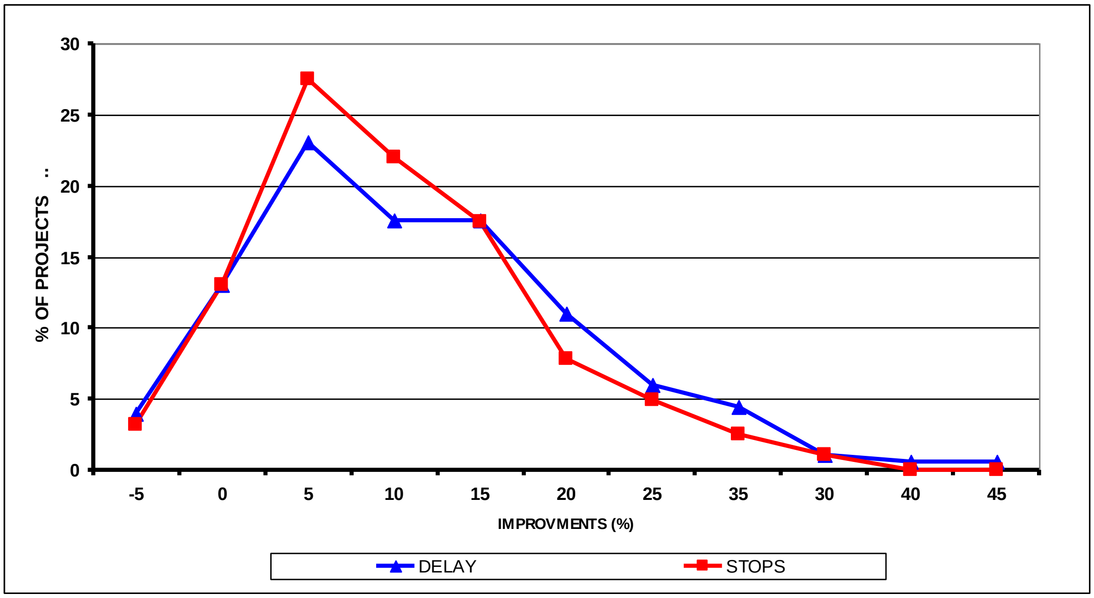


Figure 13-2 Distribution of Benefit-Signal Timing Optimization

The benefits from signal coordination were assessed based on field studies before and after using floating cars. The analysis of the field measurements from 76 projects (results were statistically significant) show that on average, travel time was reduced by 11.4 percent, delay was cut by 24.9 percent, and stops were decreased by 27 percent. Signal coordination produces major benefits for through traffic, for signal spacing up to 0.5 mile, and for moderate to heavy traffic volumes (volume/capacity > 0.6). Figure 13-3 shows the cumulative distribution of the percentage improvements in traffic performance of signal coordination. Approximately 65 percent of the projects had benefits within the 10 to 35 percent range. The variation in intersection spacing, proportion of turning traffic, and signal phasing are the main factors that influence the expected benefits between sites under the same volumes and average intersection spacing.

13.1.5 Adaptive Control Benefits

Hadi et al.[146] indicated that adaptive control systems could provide improvements in system performance compared to time-of-day (TOD) strategies in certain conditions. These systems are particularly effective during unpredictable conditions. The adaptive system benefits are higher for networks with high variations in traffic, high growth rates, and during incidents. It is expected that the benefits is higher on systems with high demand. However, no or limited benefits are expected for systems with oversaturated conditions. Hadi et al.[146] estimated based on an extensive review of

[146] Hadi, M.A., P. Sinha, and D. Jones, "Eagle Road ATMS Study," Prepared by PBS&J for The Idaho Transportation Department, Boise, Idaho, September 2005.

literature that adaptive control could reduce travel time by 5 to 7 percent during the AM and PM peak periods and 10 to 12 percent during midday and weekend periods over typical TOD plans, provided that the system is not oversaturated. However, it should be stated that some of the previous evaluation studies compared adaptive control with TOD plans that are not optimized up-to-date plans. The rationale was that these plans represent typical plans commonly used in real-world signal systems. Since the aging of TOD plans result in deteriorations in TOD plan performance, the benefits of adaptive control over these TOD plans are expected to be higher than those over well-optimized up-to-date plans. A recent evaluation of the SCATS system in Cobb County, Georgia, showed no improvements in system performance due the implementation of the system. The study concluded that the reason that the TOD plans did not improve was that they were well optimized for the conditions of the network; in other words, the adaptive control system could not find a better solution. Similar results were observed from field tests of the ACS systems developed under FHWA sponsorship. These tests have shown that the ACS systems are able to perform at least as good as well-optimized TOD plans during peak hours. This was considered a major achievement since aging of signal timing plans, particularly with high growth demand rates, can significantly deteriorate system performance.

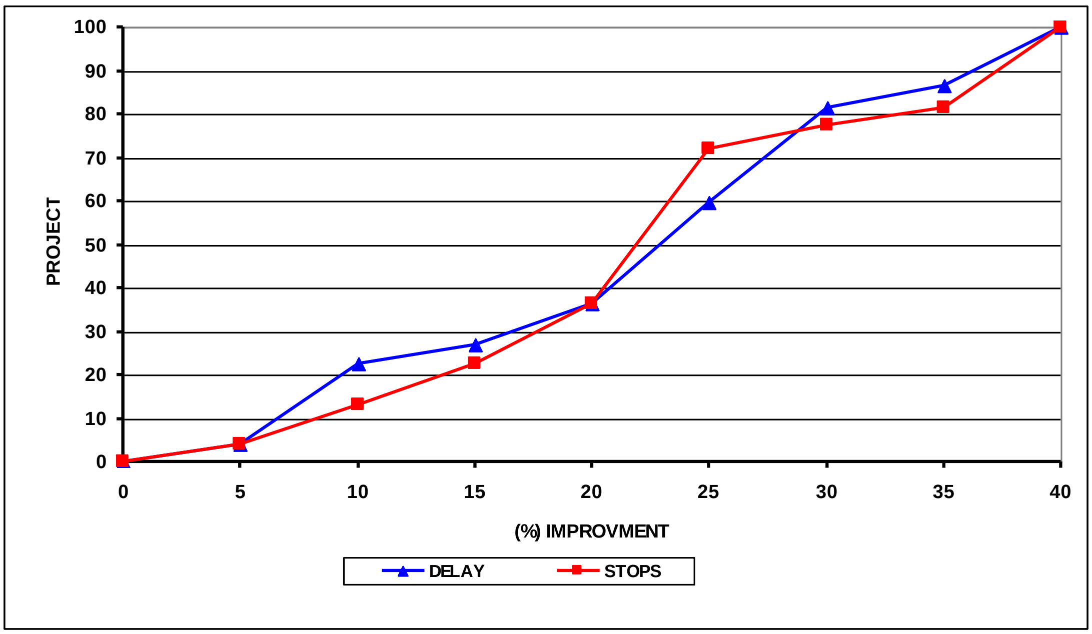


Figure 13-3 Distribution of Benefit-Signal Timing Coordinated

13.1.6 Other Evaluation Results

The following are some of the results reported in the USDOT RITA program benefit report and database:

- It decreased fuel consumption by 13 percent, decreased air emissions by 14 percent, reduced vehicle stops by 41 percent, reduced travel time by 18 percent, increased average speed by 16 percent, and decreased delay by 44 percent.
- The city of Abilene experienced the following benefits after installing a closed-loop signal system upgrade: travel time decreased by 13.8 percent, delay decreased by 37.1 percent, fuel consumption decreased by 5.5 percent, CO emissions decreased by 12.6 percent, HC emissions decreased by 9.8 percent.

According to Meyer,[147] various projects in the United States have found that:

- Interconnecting previously uncoordinated signals or pre-timed signals, and providing newly optimized timing plans and a central master control system can result in a travel time reduction of 10 to 20 percent.

- Installing advanced computer control has resulted in about a 20 percent travel time reduction compared to interconnected pre-timed signals using old timing plans.

- Installing advanced computer control has resulted in a 10 to 16 percent travel time reduction compared to non-interconnected, traffic actuated controls.

- Installing advanced computer control, compared to interconnected pre-timed control with relatively active signal timing management, has resulted in an 8 to 10 percent travel time reduction.

- Optimizing traffic signal timing plans, compared to previously interconnected signals with various master control forms and varying previous signal timing qualities, has resulted in a 10 to 15 percent reduction in travel time.

In addition to significantly reducing travel time, traffic signal control improvements also reduce stops, fuel consumption, and emissions. For example, the Texas Traffic Light Synchronization Grant Program II (TLS II) achieved reduced fuel consumption, delay, and stops by 13.5 percent (20.8 million gallons/year), 29.6 percent (22 million hours/year), and 11.5 percent (729 million stops/year), respectively. The total savings to the public in the form of reduced fuel, delay, and stops was approximately $252 million in the year after the improvements were made alone. More significantly, however, the study indicated that an average of 10 gallons of fuel was saved for every dollar that was spent on the retiming project.[148]

The FHWA's Intelligent Transportation Systems Benefits (2001 Update Report) documents that 16 to 25 percent improvement in travel times is expected by

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[147] Meyer, M., "A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility," Institute of Transportation Engineers, 1997.

[148] Fambro, D. et. al., "Benefits of the Texas Traffic Light Synchronization (TLS) Grant Program II," Texas Transportation Institute, 1995.

implementing advanced computer-based control for a region. For intersections that are interconnected, the report documents travel times improvement up to 5 to 8 percent by simply optimizing the signal timing plans. In Japan, it was found that traffic signal upgrades reduced the number of accidents by 35 to 65 percent on the studied corridors.[149]

13.1.7 Benefit Summary

Based on a review of studies summarized in the USDOT RITA benefit database, Table 13-1 through Table 13-4 present an overview summary of the results presented in previous studies.

[149] Satio, T., et. al., “Reduction of Traffic Accidents and Improvement of Road Traffic Produced by 5th Five-Year Project for the Installation and Upgrading of Traffic Safety Facilities (for ITS Deployment in Japan),” Japan Traffic Management and Technology Association, March 1998.

Table 13-1 Traffic Signal Retiming Benefits

# studies: 9				
Delay Reduction %	**Stops Reduction %**	**Travel Time Reduction %**	**Fuel Consumption Reduction %**	**Vehicle Emissions Reduction %**
[5-20]		[5-20]	[10-15]	
				[1.7-4.2]
[13-94]		[7-25]		
			[2-9]	
[16.5-24.9]	[17-27]	[7.4-11.4]		
			7.8	
			9	
22	6			
		[17-21]		

Table 13-2 Adaptive System Benefits

# studies: 21				
Delay Reduction %	Stops Reduction %	Travel Time Reduction %	Fuel Consumption Reduction %	Vehicle Emissions Reduction %
[18-20]				
21	31	13		
18.5/28.4				
			7.8	
	[28-41]			
[19-44]				
		[13-25]		
		10		
		[3-16]		
			[4-7]	[3-6]
		[10-15]		
19	10	5		
14		25		
		[7-8.6]		
15				
20				
17	22	8		
			5.7	5

Table 13-3 Computerized System Benefits

# studies: 6				
Delay Reduction %	Stops Reduction %	Travel Time Reduction %	Fuel Consumption Reduction %	Vehicle Emissions Reduction %
			13	14
44	41	18		
	33	33		
		[8-25]		
[14-30]	[28-39]	[9-14]		
			[10-12]	[5-22]

Table 13-4 Signal Coordination Benefits

# studies: 5				
Delay Reduction %	Stops Reduction %	Travel Time Reduction %	Fuel Consumption Reduction %	Vehicle Emissions Reduction %
[14-19]	[11-16]	[7-17]		
			[9-13]	[9-13]
7				
			1.6	1.2
		6.2		

13.1.8 Assessment

Based on the review presented above, the following assessment can be made regarding the evaluation of signal control improvements. The ITSOAM evaluation is limited to adaptive control. The three signal improvement alternatives evaluated in IDAS are: 1) conversion to actuated controller from pre-timed signalization, 2) signal coordination, and 3) connecting the signals to the centers. It is recommended that the options to be evaluated include:

- Improvement I: Retiming of existing coordinated signals.
- Improvement II: Coordinate existing isolated signals.
- Improvement III: Connect existing signals to a state-of-the-art computerized system (e.g., two-level or hybrid distributed system in larger cities).
- Improvement IV: Convert the existing time-of-day systems to adaptive control systems.

A combination of the above improvements may be possible. For example, improvement IV may be combined with improvement II, in case of isolated signals first coordinated and then controlled by an adaptive algorithm.

13.1.9 Signal Control Cost

Table 13-5 shows signal control cost estimates presented in the USDOT RITA cost database.

Table 13-5 Cost for Different Traffic Signal Control Improvements from the RITA Database

ADAPTIVE SYSTEM COST			COMPUTARIZED SYSTEM COST			TRAFFIC SIGNAL RETIMING COST
# studies: 1			# studies : 2			# studies: 7
#signals	total cost MUSD	cost per signal per update USD	#signals	total cost MUSD	cost per signal per Update USD	cost per signal per update USD
65	2.43	37384.6	145	8.3	57241.4	2400
			220	5.1	23181.8	3100
						3000
						3500
						[2500-3100]
						[1800-2000]
						[2000-2500]

The following costs were obtained based on a study conducted by Hamad and Hadi to upgrade the signal control systems in the Manatee-Sarasota Counties:

- Signal retiming: signal retiming was estimated at about $5,280 per signal. If the evaluation includes device replacement, an additional cost of controller and detector replacement at $18,000 per five years should be added.

- Signal coordination: this option includes cabinet and controller modifications, signal retiming, additional communication devices, cables, conduits, and pulls boxes. The cost of this option is about $20,000-$30,000 per signal.

- State-of-the-art traffic management center: this option includes the addition of state-of-the-art traffic management center, central hardware, central software, upgrade of field controllers, upgrade of communication systems, maintaining operational detectors, maintaining adequate staffing to operate and manage the system. The capital cost of this system is $30,000,000 for 520 signals (about $58,000 per signal). The annual operation and management cost is about $620,000 (about $12,000 per signal).

Previous work by Hadi et al.[150] estimated the costs of a number of adaptive signal control systems to be $500,000 per 13 intersections or about $38,500 per signal.

Note that there is an interesting agreement between the costs estimated by Hadi et al. and those included in the RITA database.

Table 13-6 presents the costs for the four alternatives in this study based on the above discussion. The user should input local values if available.

Table 13-6 Alternative Cost Estimates Per Intersection

Alternative	Capital COST	O&M Cost/Yr
I	$5,000	-
II	$15,000	$1,500
III	$57,000	$1,500
IV	$38,000	$6,000

[150] Hadi, M.A., P. Sinha, and D. Jones, "Eagle Road ATMS Study," Prepared by PBS&J for The Idaho Transportation Department, Boise, Idaho, September 2005.

13.2 Requirement Analysis

- The Tool shall allow the user to code the links of the improved corridor(s) and/or grid network(s).
- The user shall have the opportunity to request that all links of a particular facility type are improved links.
- The user can request that all links in a zone are improved links.
- The Tool shall be able to evaluate the following deployments:
    - Improvement I: Retiming of existing coordinated signals and maintaining an operational system.
    - Improvement II: Coordinate existing isolated signals.
    - Improvement III: Connect existing signals to a state-of-the-art computerized system.
    - Improvement IV: Convert the existing time-of-day systems to adaptive control systems.
- The Tool shall be able to evaluate systems with intersections coded as regular nodes or as detailed intersections coding using the “Junction” feature of Cube.
- The user shall be able to enter the number of years between the updates to the signal plans for inclusion in the calculation of benefits.
- The user shall be able to change the annual rate of increase in delay due to not retiming the signal.

13.3 Methodology

The methodology used in the developed tool to evaluate signal system control improvements is based on the review and requirements of the evaluation of traffic signal control improvements, as presented in this chapter.

The evaluation of time savings due to retiming traffic signals considers explicitly the following variables:

- Type of network modeling: The transportation network can be modeled in Cube considering detailed information for the junctions in the improved corridor (junction based), which allow for the evaluation of the benefits in terms of the reduction of the delay at the intersection and the number of stops. In case of a less detailed network modeling (which is more widely used), the benefits of the deployment can be estimated based on the estimated reduction in travel time of the approaching links.

- Reference year: The year for which the model has been calibrated.
- Project start: The year when the project is consider operational and able to give benefits.
- Project finish: The end of the life of the project and no more benefits will be perceived after this year.
- Updates: This corresponds to the retiming period.
- Deterioration in travel time with no signal retiming (default = 4 percent per year).
- Deterioration if signal retimed is done every year (default = 2 percent per year).
- Deterioration if adaptive signal control is used (default = 2 percent per year).

This Tool allows the user to evaluate the signal timing improvements listed in Table 13-7. Initial savings in travel time due to applying these improvements are also shown in Table 13-7.

Table 13-7 Improvement Types Evaluated by the Developed Tool

(a) Description of the Improvement Components

Improvement Type	Improvement Type
I	Retiming of existing coordinated signals
II	Coordinate existing isolated signals
III	Connect the existing signals to a state-of-the-art computerized system
IV	Convert the existing time-of-day systems to adaptive control systems

(b) The Evaluated Improvement Combinations

Signal timing improvement	Improvement Type Description	Improvement %
1	I	7.5
2	II	11.5
3	III	16.0
4	IV	10%
5	III combined with II	22%
6	IV combined with II or III	22%

In addition to the initial benefits presented in Table 13-7, additional drops in travel time are estimated by the methodology for the cases of signal retiming and adaptive control. Each time a signal is re-timed, the travel time is assumed to drop from the level that occurs due to the deterioration in travel time with no retiming to the level expected when the signal is retimed (see Figure 13-4). For adaptive control system, a different level of deterioration in travel time is assumed compared to time-of-day systems to consider the fact that the system can better adapt to changing traffic conditions.

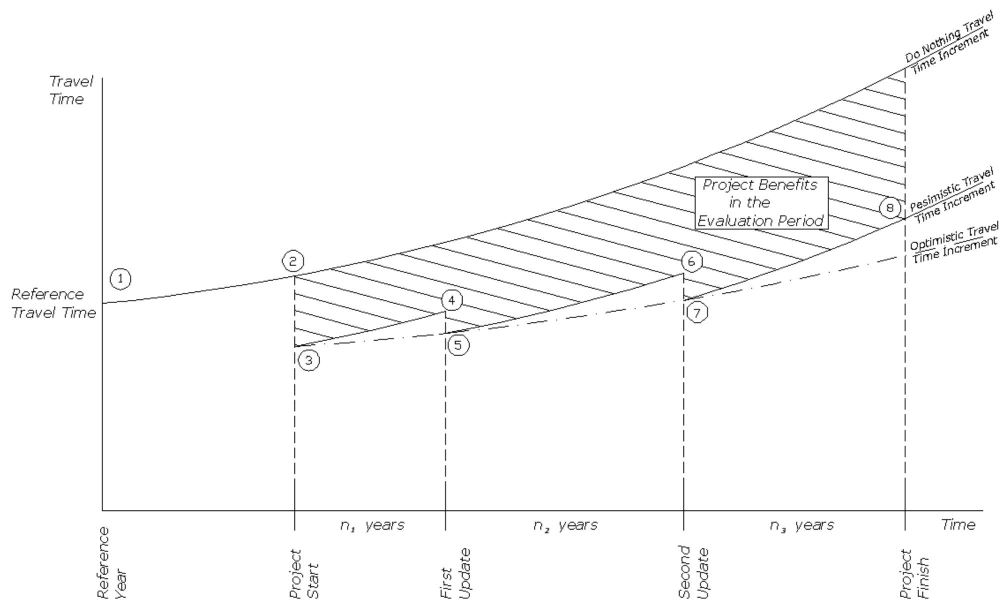


Figure 13-4 Benefit of a Traffic Signal Control Improvement

13.4 Model Implementation

The evaluation methodology presented in the previous section is implemented in the FSUTMS/Olympus model, using the script language of the Cube software. As with other evaluated ITS deployments, by selecting the signal control application from a pull down menu.

13.4.1 Modeling Structure

The modeling structure for the evaluation of traffic signal timing improvements in the developed Tool consists of three modules: 1) benefits, 2) costs and 3) performance, which are shown in Figure 13-5. For detailed implementation procedures, users should refer to the catalog in the Cube software.

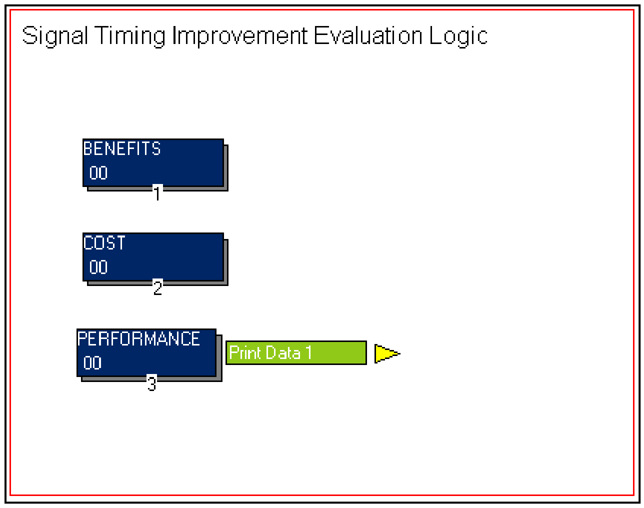


Figure 13-5 Modeling Structure for Signal Timing Improvement Evaluation

13.4.2 Input Interface

As with the other types of ITS deployments, **Error! Reference source not found.** and Figure 13-7 show that the input interface is organized into five groups, as described in Chapter 5. This section presents a discussion of the parameters that are specific to signal control evaluation.

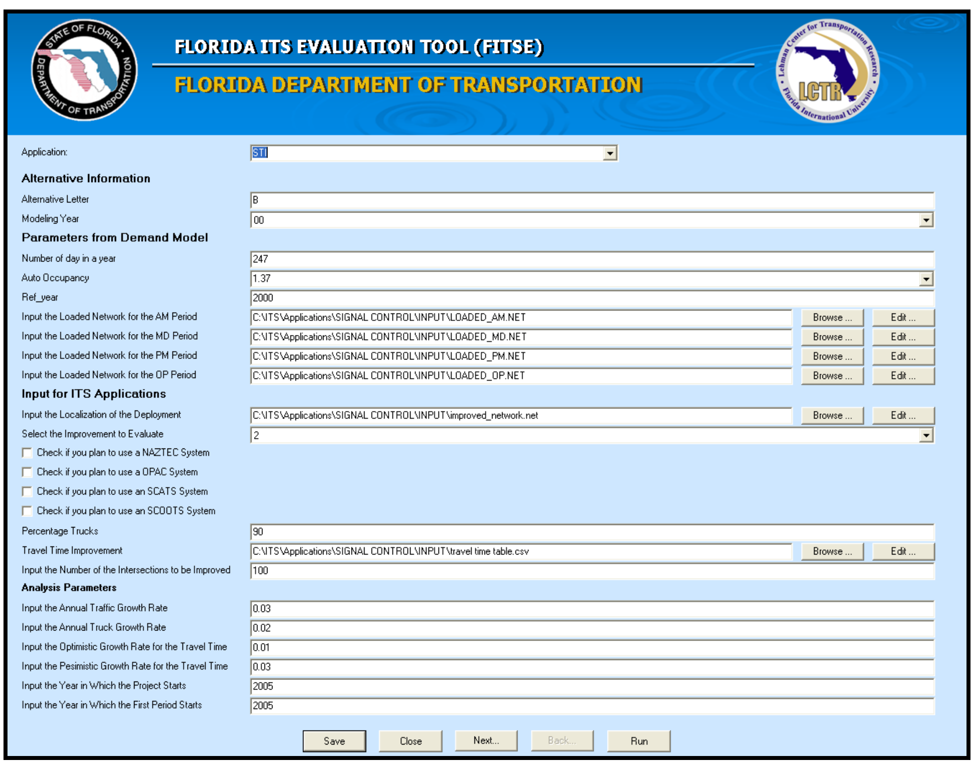


Figure 13-6 User Input Interface for Traffic Signal

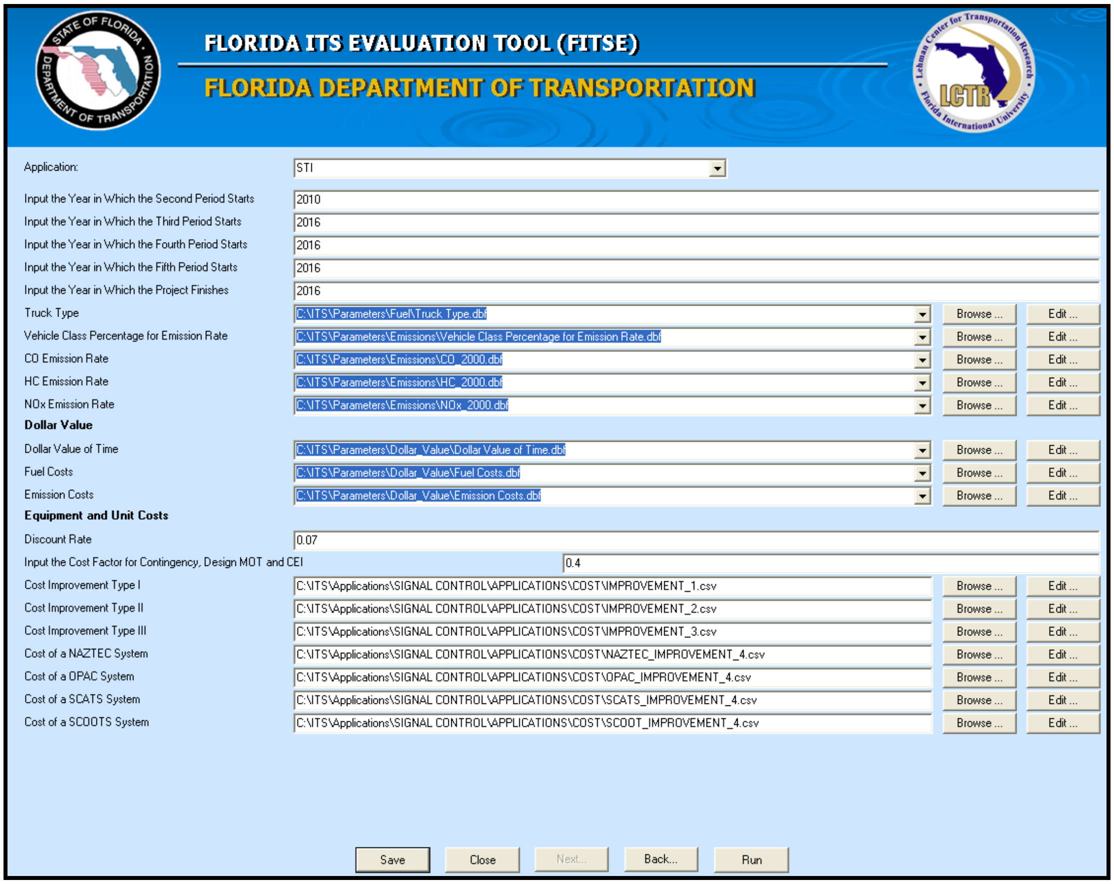


Figure 13-7 User Input Interface for Traffic Signal (Continued)

- Location of the ITS deployment: A new link attribute "IMPROVED" has been added to the link attribute list as shown in Figure 13-8. A value of 1 assigned to the attribute IMPROVED means that the link is being included as part of the improved corridor, otherwise the link is not included.

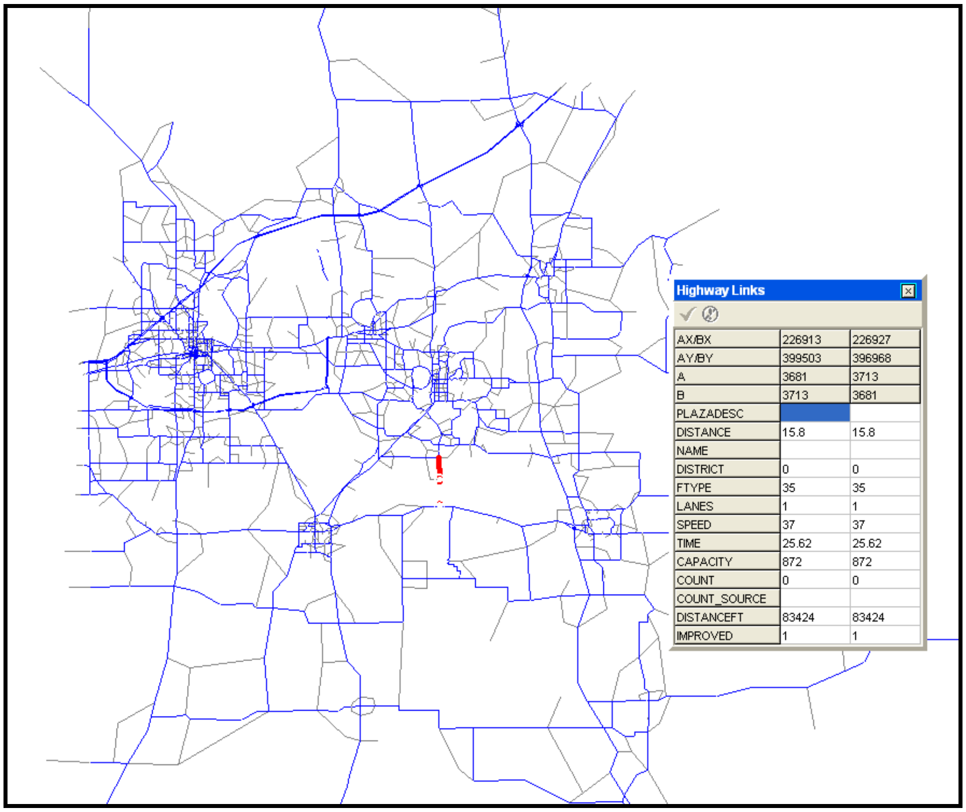


Figure 13-8 Link Attribute Window with the New "Improved" Attribute

- Deployment to evaluate (1, 2, 3, 4, 5 or 6): The user must indicate what kind of signal improvement is being analyzed.

Travel time improvement: The initial travel time improvement is a function of of the signal improvement selected for evaluation (see

- Figure 13-9).

	A	B	C
1	1	0.075	
2	2	0.115	
3	3	0.155	
4	4	0.195	
5	5	0.255	
6	6	0.305	

Figure 13-9 Link Attribute Window

- Number of intersections to be improved: The total number of intersections to be improved as part of the project. This number is not used for benefit calculations. Instead, it is used to compute the total cost of the project.

- Deterioration in travel time with no signal retiming (default = 4 percent per year).
- Deterioration if signal retiming is done every year (default = 2 percent per year).
- Deterioration if adaptive signal control is used (default = 2 percent per year).
- Project start: Corresponds to the year becomes operational.
- First project start: The year when the first timing update is done.
- Second project start: The year when the second timing update is done.
- Third project start: The year when the third timing update is done.
- Fourth project start: The year when the fourth timing update is done.
- Fifth project start: The year when the fifth user defined the timing update is done.
- Project finish: The end of the project evaluation period.

13.4.3 Output Interface

As indicated in Figure 13-10 to Figure 13-12, three standard output files are generated for signal control: 1) performance summary, 2) benefits summary, and 3) benefits and costs summary. These three files are organized under the output category in the data window.

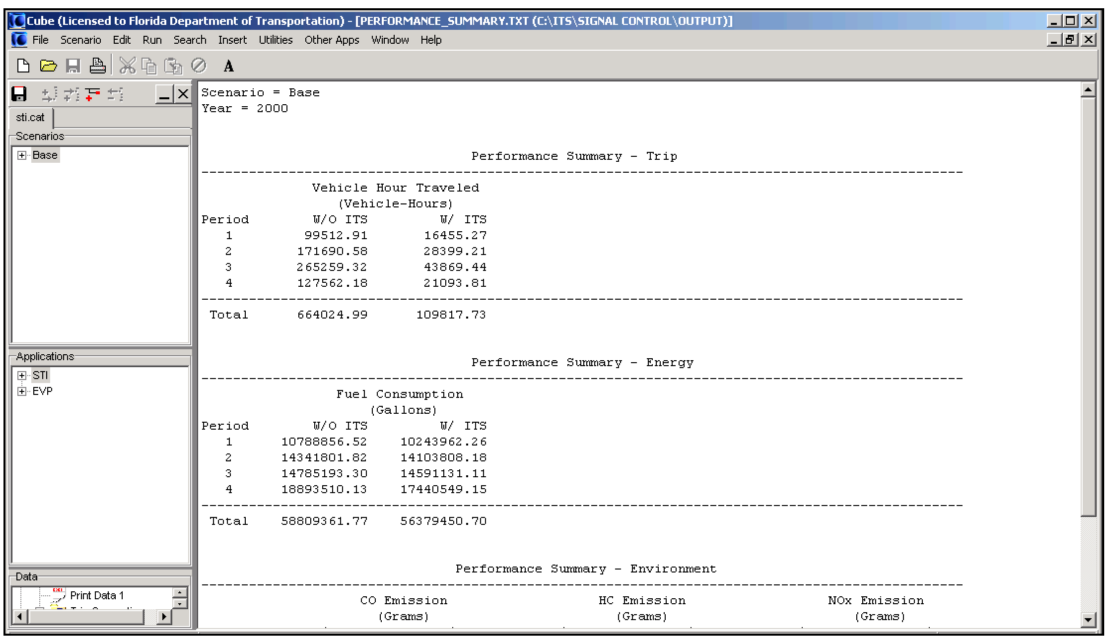
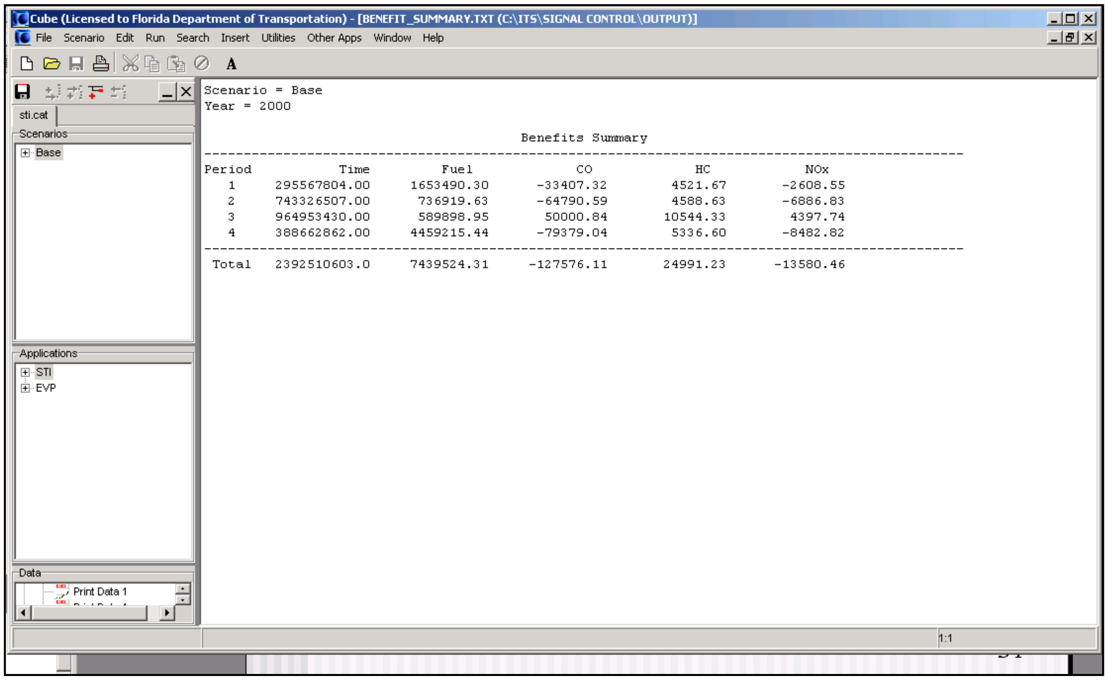


Figure 13-10 Performance Summary Output File for Signal Control

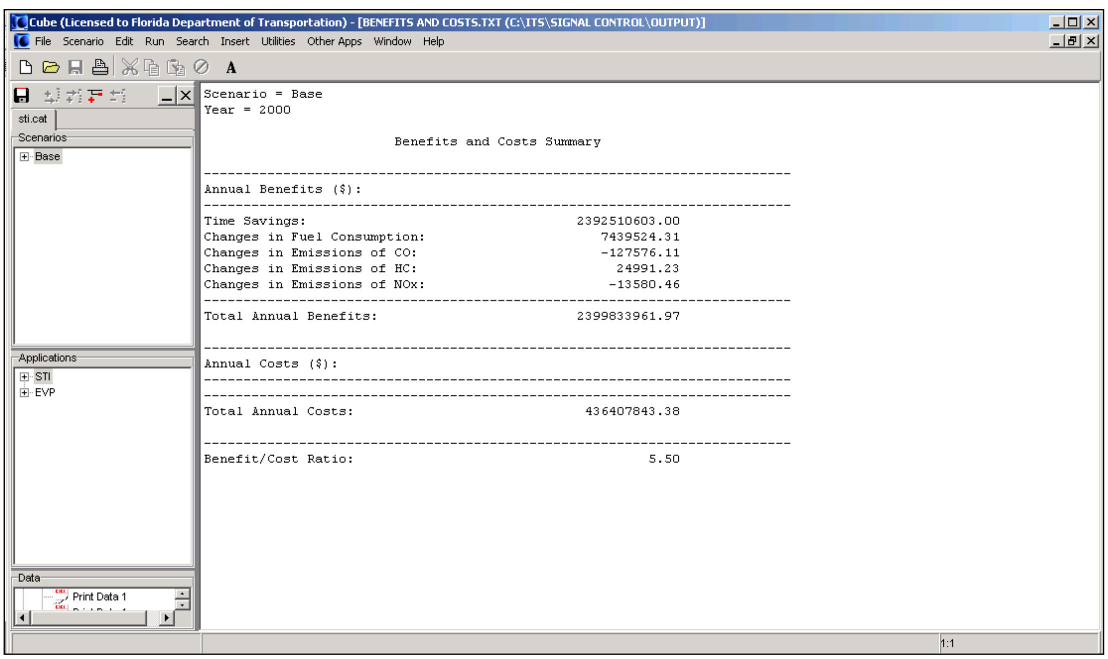


Scenario = Base
Year = 2000

Benefits Summary

Period	Time	Fuel	CO	HC	NOx
1	295567804.00	1653490.30	-33407.32	4521.67	-2608.55
2	743326507.00	736919.63	-64790.59	4588.63	-6886.83
3	964953430.00	589898.95	50000.84	10544.33	4397.74
4	388662862.00	4459215.44	-79379.04	5336.60	-8482.82
Total	2392510603.0	7439524.31	-127576.11	24991.23	-13580.46

Figure 13-11 Benefit Summary Output File for Signal Control



Scenario = Base
Year = 2000

Benefits and Costs Summary

Annual Benefits ($):

Time Savings:	2392510603.00
Changes in Fuel Consumption:	7439524.31
Changes in Emissions of CO:	-127576.11
Changes in Emissions of HC:	24991.23
Changes in Emissions of NOx:	-13580.46
Total Annual Benefits:	2399833961.97

Annual Costs ($):

Total Annual Costs:	436407843.38
Benefit/Cost Ratio:	5.50

Figure 13-12 Benefits and Costs Analysis Output File for Signal Control

14 Traveler Information Systems

Advanced Traveler Information System (ATIS) is one of the most important functional areas of Intelligent Transportation System (ITS). ATIS involves the collection, aggregation and dissemination of information to assist surface transportation travelers in moving from an origin to a destination. ATIS aims at providing the latest pre-trip and en-route traveler information such as traffic conditions, incident information, roadway construction updates, weather information, transit information, optimal routes to their destinations, and/or traveler services. Such information helps travelers making informed travel decisions regarding their departure time, mode of travel and route, thus reducing their delays and improving the trip travel time reliability. ATIS have involved the use of a number of technologies for disseminating traveler information ranging from traveler information telephone systems (e.g., 511 systems), web sites applications, information kiosks/displays, personal handheld computers, and dynamic in-vehicle navigation and information systems. Although highway dynamic message signs (DMS) and Highway Advisory Radio (HAR) are used to disseminate information to drivers, these two types of technologies have been categorized as Advanced Traffic Management Systems (ATMS) devices by the National ITS Architecture (NITSA).

14.1 Previous Approaches to Evaluation

This section presents a review of tools and studies that address the evaluation of improvements to ATIS.

14.1.1 Methodology Used in SCRITS

Below is a description of how SCRITS evaluates ITS systems.

- The benefits and costs of traffic information through the internet is calculated based on the user inputs of the percentage of trips for which the internet access is available (default = 10 percent), the percentage of people who look at the information before they depart (default = 10 percent), the percentage of people that save time (default = 20 percent), and the average delay savings (default = 3 minutes). The users can modify the default values.
- The benefits of pager services are calculated based on the percentage of trips where incidents could impact route decision (default = 20 percent), percentage of drivers that have the system (default = 20 percent), percentage of those drivers that have the system activated during their trips (default = 50 percent), percentage of drivers with activated systems that can save time (default = 25 percent), and amount of time saved by each driver who is saving time (default = 5 minutes).

14.1.2 Methodology Used in IDAS

For each link covered by the ATIS web site and/or telephone system, the delay time is first calculated as the summation of incident delay and the difference between the loaded and free-flow travel time. The link delays are then converted to the avoided delay per trip for each O-D pairs.

The avoided delay between each O-D pairs is calculated by multiplying the number of O-D trips, market penetration (proportion of travelers using of the information), no-coverage delay time (defined as the difference between the loaded travel time and the free-flow travel time plus the incident delay time), and the delay saving rate due to ATIS. The total saving is then obtained by summing the savings over all the O-D pairs.

The following are the defaults used for the ATIS telephone system benefit calculations:

- The percentage of travelers that call the information system is 0.5 percent.
- The resulting maximum amount of time saving is 15 percent of the no-coverage delay time when the market penetration is less than 10 percent, and 0 percent of the no-coverage delay time when the market penetration is 60 percent or greater.

The benefits of the ATIS web site are calculated in the same way as that of the telephone-based traveler information systems but with different defaults as follows:

- The market penetration is 0.5 percent for the year 2000, 5 percent for the year 2005, 10 percent for the year 2010, 20 percent for the year 2015, 30 percent for year 2020, and linear interpolation for year 2020 and beyond.
- Maximum amount of time saving is 20 percent of the no-coverage delay time when the market penetration is less than 10 percent, 10 percent of the no-coverage delay time for 40 percent market penetration, and 0 percent of the no-coverage delay time for 60 percent market penetration or greater.

The Ohio-Kentucky-Indiana regional council of governments performed an IDAS analysis of Advanced Regional Traffic Interactive Management Information System (ARTIMIS). The traveler advisory telephone service (TATS) was part of the system. The study results showed that the whole system could produce a daily time savings of 300 vehicle-hours for travelers during the AM peak period, and 500 vehicle-hours for travelers during the PM peak period. The total estimated benefit/cost ratio for this system was 12:1. The Michigan Department of Transportation (MDOT) used IDAS to investigate the impacts of Temporary Traffic Management Systems (TTMS) on their roadway networks and the benefits associated with it during the reconstruction period of I-496 in Lansing, Michigan. The system consisted of various ITS components including telephone-based and web-based traveler information systems. A benefit/cost ratio of 3.2:1 was obtained for this system. Kristof et al. used IDAS to evaluate ATIS projects in the State of Washington. Based on the ATIS studies in Washington State and elsewhere, a number of adjustments to the default values in IDAS, such as market penetration and percentage of time saved, were suggested. The market penetration used for the telephone-based information system was 10 percent, and that for the web-based information system was 3 percent in 2000, 8 percent in 2005, 13 percent in 2010, 20 percent in 2015, and 30 percent in 2020.

14.1.3 ITSOAM

The ITS Options Analysis Model (ITSOAM) is specifically designed for the State of New York, to estimate the benefits of deploying ITS including non-subscription traveler information services such as telephone, web/internet, and kiosks. The benefits due to the implementation of non-subscription information services are considered in three situations, namely, non-recurrent events related to the incidents on the freeways, and scheduled non-recurrent events with or without the capacity reduction. For each setting, the information is further classified as pre-trip information and en-route information, which may have different responses from travelers. The reduction in delay due to the implementation of ATIS is evaluated by using a queuing analysis approach, in addition to the consideration of other associated benefits, such as safety, fuel consumption and emissions. The ITSOAM user guide[151] recommends a market penetration rate in the range of 25 to 45 percent and 30 to 70 percent for pre-trip and en-route information acquisition, respectively (35 percent default for pre-trip and 50 percent default for en-route). Additionally, they recommended using 15 to 45 percent of the compliance rate for basic information services, and 25 to 55 percent of compliance rate for advanced information systems.

ITSOAM recognizes that vehicles that exit the freeway and bypass the incident bottleneck are delayed beyond the normal non-incident time on the freeway section. The travel time on the alternate route is assumed to be a constant percentage above the incident-free traversal time on the main freeway section. Mannering's[152] survey of Seattle commuters revealed that, on average, the trip travel time on the shortest alternate route was about 25.7 percent longer than the most frequently used route during peak hours of the day. A study of urban route selections in Rome, Italy[153] indicated that the alternative routes were 8 to 29 percent longer than the shortest route available. The ITSOAM assumes that the travel time on the impacted roadway in normal conditions is 15 percent lower than the travel time on alternative routes.

[151] Thill, J.C. and G. Rogova, "The ITS Options Analysis Model Technical Documentation," Produced for the New York DOT by Calspan UB Research Center and University at Buffalo, Buffalo, NY, October 13, 2005.

[152] Mannering, F.L., "Poisson Analysis of Commuter Flexibility in Changing Routes and Departure Times," Transportation Research Part B, 23(1), pg. 53-60,1989.

[153] Tagliacozzo, F. and F. Pirzio, "Assignment Models and Urban Path Selection Criteria: Results of a Survey of the Behaviour of Road Users," Transportation Research, 7, pg. 313-329,1973.

14.1.4 Compliance Rate and Market Penetration

The method used in this study to evaluate ATIS requires the use of a number of benefit and cost parameters. Below is a brief discussion of the selected parameter values.

Compliance Rate (*CR*)

Several researchers have used the stated preference approach in an attempt to determine the percentage of travelers changing trip decisions in response to information disseminated by ATIS technologies. The studies concluded based on this type of surveys that the disseminated information can result in up to 60 to 70 percent of the freeway traffic exiting the freeway ahead of a bottleneck, like an incident location.[154,155,156,157] However, information about the actual diversion due to traveler information has been limited. Several European field studies have found that dynamic message signs (DMS) compliance rates range between 27 to 44 percent.[158] The compliance rate in the case of phone-based and web-based ATIS, particularly during lane blockage conditions, is expected to be much higher than the rate for DMS since travelers calling 511 or accessing the web are more likely to modify their behaviors to save time.

Mahmassani,[159] and Liu and Mahmassani[160] assumed that travelers switch routes under information based on a boundedly rational switching behavior with travelers not changing their routes as long as the difference between travel time on the subject route and alternative route is below a certain threshold. For travelers to switch route, travel time savings should be at least a certain percentage less than the travel time on

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[154] Madanat, S., C.Y. Yang, and Y.M. Yen. "Analysis of Stated Route Diversion Intentions under Advanced Traveler Information Systems Using Latent Variable Modeling." Transportation Research Record, No. 1485, 1995, pp. 10-17.

[155] Benson, B.G. "Motorist Attitudes about Content of Variable-Message Signs." Transportation Research Record, No. 1550, 1996, pp. 48-57.

[156] Barfield, W., L. Conquest, J. Spyridakis, and M. Haselkorn. "Information Requirements for Real-Time Motorist Information Systems." Proceedings of the Vehicle Navigation and Information Systems Conference (VNIS), New York, IEEE, 1989, pp. 101-112.

[157] Chatterjee, K., N.B. Hounsell, P. E. Firmin, and P. W. Bonsall. "Driver Response to Variable Message Sign Information in London." Transportation Research Part C, Vol. 10, No. 2, 2002, pp. 149-169.

[158] Tarry, S., and A. Graham. "The Role of Evaluation in ATT Development." Traffic Engineering and Control, Vol. 36, No. 12, 1995, pp. 688- 693.

[159] Mahmassani, H.S. "Dynamic Models of Commuter Behavior: Experimental Investigation and Application to the Analysis of Planned Traffic Disruptions." Transportation Research A, Vol. 24, No. 6, 1990, pp.465-484.

[160] Liu, Y. H., and H.S. Mahmassani. "Dynamic Aspects of Commuter Decisions under Advance Traveler Information Systems – Modeling Framework and Experimental Results." Transportation Research Record, Vol. 1645, 1998, pp. 111-119.

the current path and at least less than a certain absolute time. These two thresholds were assumed to have a mean of 1 minute and 20 percent respectively, determined empirically from user behavior studies under information.

Peeta et al.[161] investigated the impacts of DMS information content and other relevant factors on diversion rates using the Stated Preference method. The results indicated that 53 percent of the drivers would divert to an alternative route when the expected delay on the current route is greater than 10 minutes. Based on a stated preference survey, Khattak et al.[162] found that 42.9 percent of respondents would definitely take alternative routes under jammed conditions. Huchingson and Dudek[163] developed a linear relationship between the diversion rate and posted incident delays on the DMS, with zero diversion for zero delay and 95 percent diversion for one hour delay.

Market Penetration (*MP*)

The evaluation conducted by Yim, et al.[164] of the TravInfo regional ATIS in the San Francisco Bay Area, from September 1996 to September 1998, showed that only 9 percent of households were aware of this system and very few of them had ever tried the system. The results of Yim, et al.'s[165] 2002 update indicated that 4 percent of the household survey respondents were using the Internet, 18 percent were using telephone as a source of pre-trip information, and 2 percent were using cell-phone as a source of en-route information. A study by Pierce & Lappin[166] of the Seattle ATIS indicated that travelers acquire information on only about 10 percent of their trips and they change their travel plan during 9 percent of these acquiring trips. This indicates that the percentage of travelers that may benefit from the system is only 0.09 percent.

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[161] Peeta, S., J.L. Ramos, and R. Pasupathy. "Content of Variable Message Signs and On-line Driver Behavior." Presented at Transportation Research Board 79th Annual Meeting, Washington DC, January 9-13, 2000.

[162] Khattak, A.J., F.C. Koppelman, and J.L. Schofer. "Stated Preferences for Investigating Commuters' Diversion Propensity." Transportation, Vol. 20, 1993, pp. 107-127.

[163] Huchingson, R.D. and C.L. Dudek. "Delay. Time Saved, and Travel Time Information for Freeway Traffic Management." Transportation Research Record: Journal of the Transportation Research Record, No. 722, TRB, National Research Council, Washington, D.C., 1979, pp. 36-40.

[164] Yim, Y., and M. Miller. "Evaluation of TravInfo Field Operational Test." Published by California PATH Program, University of California, April 25, 2000.

[165] Yim, Y., A.J. Khattak, and J. Raw. "Traveler Response to New Dynamic Information Sources: Analyzing Corridor and Area-Wide Behavioral Surveys," Presented at 81st Annual Meeting of the Transportation Research Board, Washington, D.C., 2002.

[166] Peirce, S. and J. Lappin. "Why Don't More People Use Advanced Traveler Information? Evidence from the Seattle Area." Presented at 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., January 2004.

A 511 study[167] indicated that the number of calls per day could range from 1.5 to 2.5 percent of the region's population, depending on the geographical conditions of the area, the configuration of the transportation network, and the amount of congestion in the area. For example, the Boston SmarTraveler is estimated to have received approximately 4.5 million calls in 2001. That could be translated into about 1.2 calls per person per year based on the Boston metropolitan area population.

14.2 Assessment

The above review indicates that one of the most important parameters that must be identified in the evaluation of ATIS is the percentage of travelers benefiting from the information provided. This percentage can be obtained by multiplying the market penetration of an ATIS service by the compliance rate. The market penetration is the percentage of travelers that access the information while the compliance rate is the percentage of these travelers that make changes in trip decisions based on the information. The preceding discussion indicates that there is a wide variation of the default values used by existing evaluation tools for the percentage of travelers benefiting from the system. IDAS assumes that this percentage is 0.5 percent for both phone-based and web-based ATIS for the year 2000. It assumes that this percentage increases by about 1 percent every year for the web-based ATIS but not for the telephone-based ATIS. Users of IDAS have changed these default values, with one study decreasing it to 0.42 percent, another study increasing it to 1.4 percent, and yet another study increasing it to 10 percent . The default used by ITSOAM for the percentage of user benefiting from ATIS while en-route is about 12 percent for basic information and 18 percent for advanced information, which is significantly higher than the default values used in IDAS for the existing conditions. The value of the percentage of traveler benefiting from the system is very important in estimating the benefits of ATIS. Thus, detailed examination of past studies on the subject is presented later in this paper.

When calculating the ATIS benefits in IDAS, the reduction in delay due to ATIS is assumed to be a fixed percentage of the total delay mainly incurred due to incidents. It may be argued that the percentage saving is a function of the traffic conditions during the incident both on the original and the alternative routes. Thus, ATIS evaluation methods should attempt to take these conditions into consideration.

14.3 Requirement Analysis

Below are the requirements for ATIS evaluation:

[167] Yim, Y., and M. Miller. "Evaluation of TravInfo Field Operational Test." Published by California PATH Program, University of California, April 25, 2000.

- The Tool shall allow the user to specify that it will perform the evaluation of a traveler information system for the region.

- The Tool shall allow the evaluation of regional ATIS telephone/website implementations.

- The Tool shall consider compliance rate and market penetration of ATIS in the evaluation.

    - Default values should be provided for the compliance rate and market penetration.
    - The user shall be able to change the default values of compliance rate and market penetration.

- The Tool shall include a method to estimate the regional savings in incident delay due to telephone and web site traveler information.

14.4 Methodology

This section discusses the methodology used in this project for evaluating ATIS alternatives.

14.4.1 Effects of ATIS on Delay

As in IDAS, the main benefits of ATIS that can be converted to dollar values are assumed to result from changes in traveler trip decisions that are induced by the provided information. The proposed methodology, however, differs from the IDAS methodology in that it calculates the delay saving rather than using a fixed percentage. The method considers the impact of ATIS on freeways and arterial streets using different incident delay assumptions for these two types of facilities, unlike the methodology used in IDAS that only considers the freeways. Finally, the methodology utilizes estimates of the benefit and costs parameters that were obtained based on detailed investigation of Florida ATIS databases and previous studies on the subject.

The methodology calculates the delays due to incidents with and without ATIS based on relationships developed by Cohen and Southworth.[168] These relations were developed using queuing theory equations based on incident frequency and incident duration data collected by Sullivan et al.[169] The expressions are presented below.

[168] Cohen, H. and F. Southworth, "On the Measurement and Valuation of Travel Time Variability Due to Incidents on Freeways," *Journal of Transportation and Statistics*, December 1999, pp. 123-131.

[169] Sullivan, E., S. Taff, and J. Daly, "A Methodology for Measurement and Reporting of Incidents and Prediction of Incident Impacts on Freeway," Report prepared for the U.S. Department of

For freeways with two lanes in each direction, the developed relationship is:

$$\mu_d = 0.0154(\frac{V}{C})^{18.7} + 0.00446(\frac{V}{C})^{3.93} \quad (14\text{-}1)$$

For freeways with three lanes in each direction, the developed relationship is:

$$\mu_d = 0.0127(\frac{V}{C})^{22.3} + 0.00474(\frac{V}{C})^{5.01} \quad (14\text{-}2)$$

For freeways with four lanes in each direction, the developed relationship is:

$$\mu_d = 0.00715(\frac{V}{C})^{32.2} + 0.00653(\frac{V}{C})^{7.05} \quad (14\text{-}3)$$

In the above equations, μ_d represents the average incident delay rate in vehicle hours per vehicle mile, and *V/C* is the ratio of volume to capacity.

The relationships presented above were derived for freeway segments. Not much work has been done to estimate the impacts of incidents on arterial delays. Yang et al.[170] found that the delay due to an incident on a signalized arterial street is 15 to 34 percent higher when there are signals on the highway segment compared to the segments without signals (uninterrupted-flow segments). In addition, the incident frequency and average duration is expected to be different on arterials compared to freeways. Based on queuing theory equations, the relationship between incident delay on signalized arterials and those on freeways can be calculated as follows:

$$\mu_{d,s} = \mu_{d,u} \times \frac{f_s}{f_u} \times (\frac{t_{R,s}}{t_{R,u}})^2 \times a_s \quad (14\text{-}4)$$

where $\mu_{d,s}$ represents the arterial incident delay rate while $\mu_{d,u}$ denotes the freeway incident delay rate in vehicle hours per vehicle mile. f_s and f_u refer to the incident frequency for arterials and freeways, respectively, and $t_{R,s}$ and $t_{R,u}$ are the corresponding incident durations. The parameter a_s accounts for the additional incident delay on signalized arterial streets compared to uninterrupted flow highways. In this study, a comparison was made between incident statistics from freeway corridors in Broward County, FL and incident statistics for an urban arterial street (US-1) in Miami-Dade County, FL. Both of these corridors are located in South Florida. It was found that the incident rate is 0.616 per million vehicle-mile for the freeway and 0.38 per million vehicle-mile for the arterial street.[171,172] The ratio of the average arterial incident duration to freeway incident duration was found to be 0.54.

[170] Transportation, Federal Highway Administration. San Diego, CA: Ball Systems Engineering Division. 1995.

[171] Hadi, M. and C. Zhan, "*Benefit-Cost Analysis of FDOT District 4 SMART SunGuide ITS Operations, Final Report*," Prepared for Florida Department of Transportation (FDOT) District 4, January, 2006.

[172] Zhu, X, "Design Strategies for an Artificial Neural Network Based Algorithm for Automatic Incident Detection on Major Arterial Streets," Submitted to Institute of Transportation Engineers for the Daniel B. Fambro Student Paper Award Competition, March 31, 2008.

Based on the conclusions of the Yang et al.[173] study mentioned earlier in this section, the default value for the parameter a_s in Equation 4 was assumed to be 1.25. Substituting all of the above values in Equation 4, the relationship between the arterial incident delay rate and freeway incident delay rate can be expressed as:

$$\mu_{d,s} = 0.22\mu_{d,u} \tag{14-5}$$

The total annual incident delay with and without ATIS scenarios were calculated by multiplying the incident delay rate in vehicle-hours per vehicle-mile by the vehicle-miles traveled per year for each highway segment covered by ATIS. The values of the vehicle miles traveled during incident conditions per year are calculated based on the total annual link volume, incident frequency per year and incident duration.

The benefits of ATIS are then calculated by assuming a certain percentage of traffic flow during incident conditions divert from the incident location and thus reduce the vehicle-miles traveled at the incident location as follows:

$$q_{ATIS} = q_{No\_ATIS} \times (1 - MP) \times (1 - CR) \tag{14-6}$$

where q_{ATIS} and $q_{\text{No\_ATIS}}$ are the volumes of the traffic joining the queue during incidents with and without ATIS, respectively. *MP* denotes the market penetration and *CR* is the compliance rate. The values of the *MP* and *CR* parameters will be discussed in the next section.

The calculation of the benefits in this study accounts for the fact that the diverted vehicles will most likely experience additional travel time due to diverting to the alternative routes compared to the travel time on their original route without incident. This additional travel time is estimated and subtracted from the travel time benefits due to the reduction in queue length during incidents that results from traffic diversion. To calculate this additional travel time, it is assumed that a certain proportion of the diverted travelers will divert to freeway segments and the remaining diverted travelers will divert to arterial streets. These proportions and the additional length of the alternative route will have to be estimated by the user of the methodology since they vary depending on local conditions. The average travel time on the alternative freeway and arterial routes are then calculated based on the average volume and average capacity of each of these two facility types, considering the additional traffic diverting to these routes due to incidents. The additional time on the alternative route can then be calculated as the sum of the additional travel time on the freeway and arterial alternative routes.

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[173] Yang, S., F. Mei, and M. Hadi, "Estimation of Incident Delays on Arterial Streets," Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., January 13 – 17, 2008.

Selection of *CR* and *MP* Parameters

In this study, the statistics of 511 calls and web access in South Florida were obtained from the Smart Traveler Information in South Florida for the years 2005 to 2007. It was found that the number of phone calls ranged between 200,000 to 300,000 per month and the number of website users ranged from 50,000 to 70,000 per month. Based on these numbers and the number of trips in South Florida, the percentage of the user of the 511 and traveler information web systems was estimated using the following equation:

$$MP = \frac{N_{ATIS}}{N_{trips}} \tag{14-7}$$

where N_{ATIS} is the sum of 511 calls and web uses and N_{trips} is the total number of trips per year estimated based on the travel demand model results. The default *MP* value is estimated to be 1 percent based on the results of Equation 10 as well as in consideration of the values reported in the literature as discussed earlier. An additional 0.5 percent increase per year is assumed along with the assumption that aggressive marketing policy and advancement in information dissemination technologies will increase market penetration. The change of market penetration with time is illustrated in Figure 14-1. Based on the studies reviewed above, the compliance rate is assumed to be a function of the estimated delay saving due to diversion with 0 percent diversion for 0 minutes estimated saving in delay, 20 percent for 15 minutes saving in delay, 50 percent for 30 minutes saving in delay, and 100 percent for 45 minutes or more saving in delay, as shown in Figure 14-2. However, when using the developed tool and methodology, the *MP* and *CR* may be updated to reflect local experiences with these systems and to account for new information that becomes available on the subject.

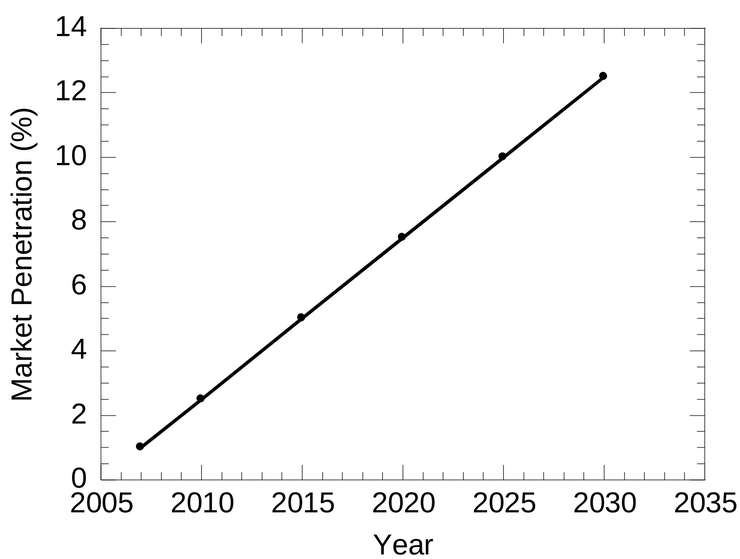


Figure 14-1 Default Market Penetration

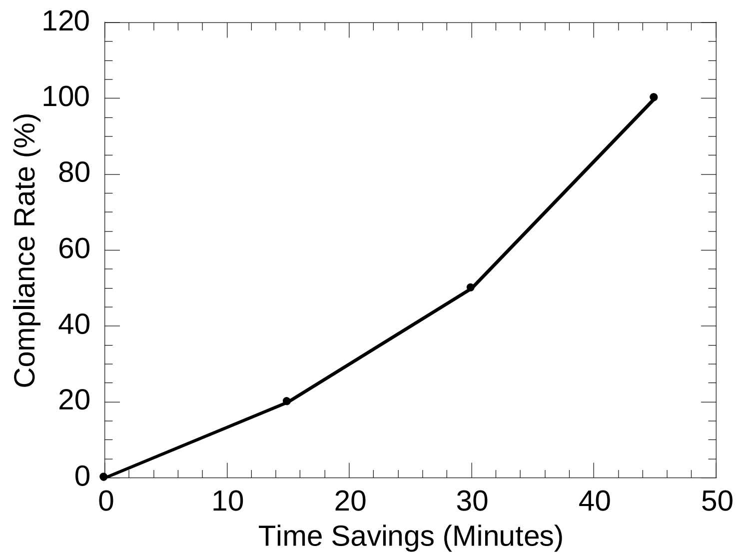


Figure 14-2 Compliance Rate

14.5 Cost

An accurate estimation of the capital and recurrent (operation and management) costs is required for a reliable benefit and cost analysis of ATIS. Accounting accurately for all the costs involved in an ITS project can be a challenging task. IDAS estimates the cost of telephone-based and web-based ATIS as the cost of the hardware, software, integration, in addition to labor at TMC and information service provider (ISP) centers. When summing the costs of the different components included by IDAS for ATIS equipment at the information service provider (ISP) and traffic management centers (TMC), the total capital cost of the implementation ranges between $533,000 and $881,000 with an operation and management cost ranging between $285,000 and $395,000. An additional cost is estimated for the communications between the TMC and the ISP, assuming the use of leased DS3 communication line at a recurrent cost of $24,000 to $72,000 per year. The above costs were estimated before the widespread implementations of 511 and web-based systems. These implementations allow more detailed examination of the required components for these systems and the costs associated with these components.

An estimate of ATIS costs should include the costs required for data gathering, data fusion and processing, telephonic dissemination platform, 511 code implementation, and continuing marketing campaign.[174] A number of reports were reviewed to determine the potential costs of these components.[175,176,177,178,179,180] Table 14-1

[174] “511 America’s Traveler Information Number Deployment Assistance Report #1: Business Models and Cost Considerations.” Published by the 511 Deployment Coalition, January 2002.

[175] Santana, R., et al. “The 511 South Florida Status Report,” Miami, FL, October 2007.

presents cost estimates identified in this study based on the review of these documents.

Table 14-1 Estimates of the Costs of ATIS Deployment by Component

Component	Types of Elements Contributing to Costs	Factors Affecting Costs	Cost Range in Dollars*		
			Small area*	Medium area*	Large Area*
Data Collection	Detectors, cameras, automatic vehicle identification/ location etc.	Size and type of network.	No cost is added. It is assumed in this study that detection and surveillance infrastructure already exist as part of TMC operations. However, user can add the costs if needed.		
Data Fusion	Integration with TMC software and fusion and management of data from multiple sources	Size, nature and attribute of the integrated system	150,000 (20,000)	300,000 (30,000)	500,000 (50,000)
Telephonic Dissemination Platform and Website	Interactive voice recognition (IVR), web site, telephone lines	System size, number of calls, and system features	150,000 (25,000)	350,000 (60,000)	650,000 (100,000)
511 Dialing Cost	Call routing, 511 translation, and toll free translation	Number of calls	25 cents per call. In this study this will be calculated based on the estimated number of calls		
Marketing	Radio advertisement, signs, brochures, etc.	Size of region	(50,000)	(200,000)	(400,000)

*The number in brackets is the recurrent cost while the number outside the bracket is the capital cost.

As indicated in Table 14-1, the 511 dialing cost is a function of the number of calls made to the system. When calculating this cost, the number of calls is estimated based on the total number of trips and the market penetration. For additional confirmation,

[176] Raman, M., and C. Zimmerman. "What Does It Cost to Deploy 511? A Case Study," Presented at 511 Deployment Coalition Meeting, Chicago, IL, July 21-22, 2005.

[177] Berman, M. "Southeast Florida ATIS Management Plan." Prepared for FDOT, Tallahassee, FL, May 2006.

[178] Sherer, E. "Preliminary Detail and Budget Estimate for ATIS and Telecommunications Components." Prepared for FDOT, Tallahassee, FL, April 2003.

[179] Sanders, D., J.J. Sluss, and Radhakrishnan. "Deployment Plan - 511 Traveler Information Services." Prepared for the Oklahoma Department of Transportation by the Oklahoma Transportation Center, OTC Report 2005-1, Norman, Oklahoma, January 2005.

[180] "511 Deployment Costs: A Case Study." Published by The 511 Deployment Coalition, November 2006.

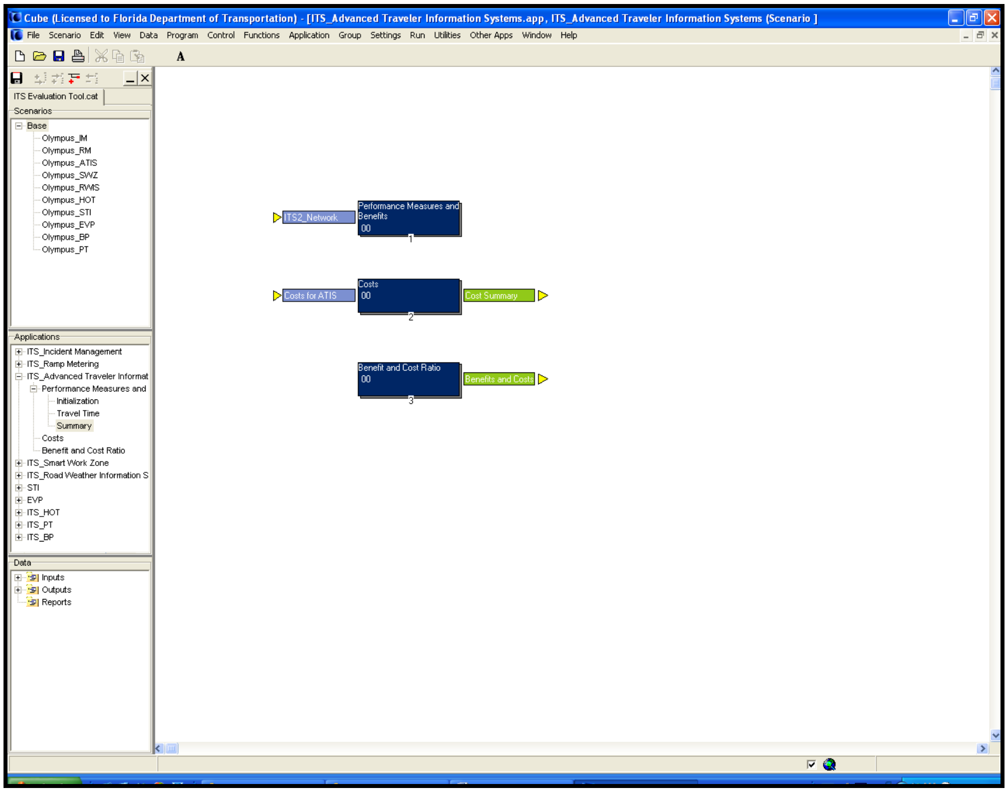
the research team obtained the cost of implementing and operating the Southeast Florida ATIS system from the FDOT. The Southeast Florida region includes Miami, Broward, and Palm Beach counties. The Southeast Florida ATIS is managed by a private-sector ISP and includes both a 511 and a web-based traveler information system. This system has included minimal field deployment of field devices since it utilizes to a large extent the information gathered by the traffic management centers in the region. The combined capital and recurrent cost of this system for an eight-year period, since it became operational, is $11,777,968. This translates to an average of about $1,400,000 per year. The cost estimate based on the numbers presented in Table 1 is $1,469,224 per year. In comparison, IDAS estimates of the cost of ATIS phone and web site to be $914,631 per year.

14.6 Implementation

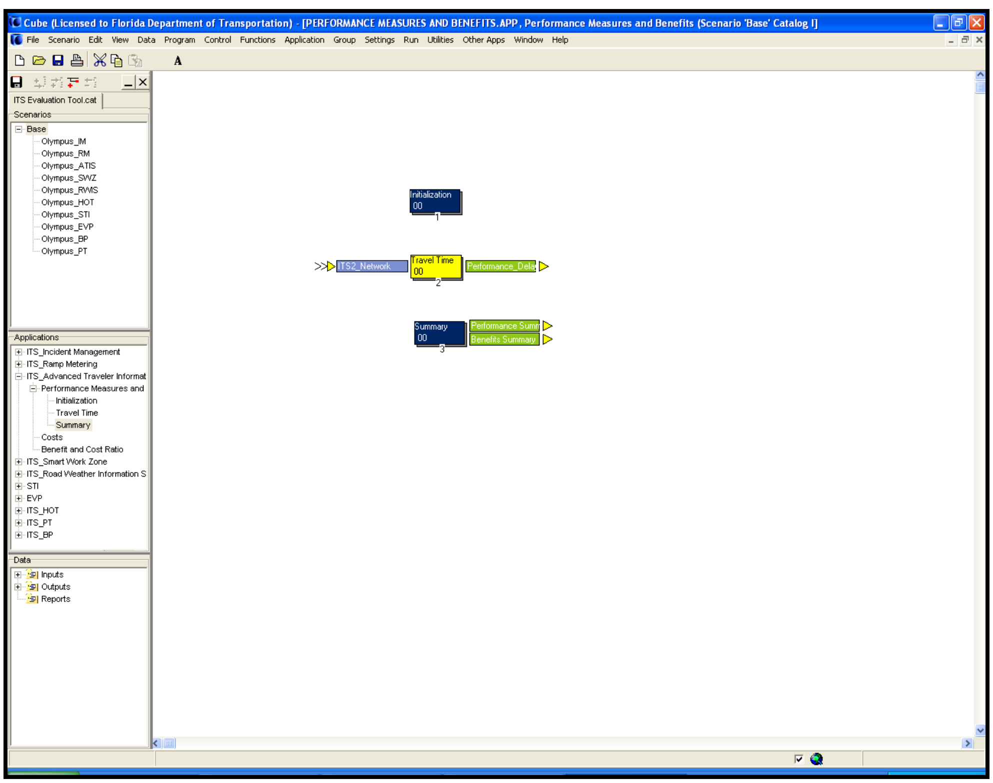
The evaluation methodology presented in the previous section is implemented in the FSUTMS/Olympus model, using the script language of the Cube software. As with other evaluated ITS deployments, the signal control application selects this option from a pull down menu.

14.6.1 Modeling Structure

The modeling structure for the ATIS evaluation in the developed tool consists of three modules: 1) benefits, 2) costs, and 3) performance, which are shown in Figure 14-3. For detailed implementation procedures, the user should refer to the catalog in the Cube software.

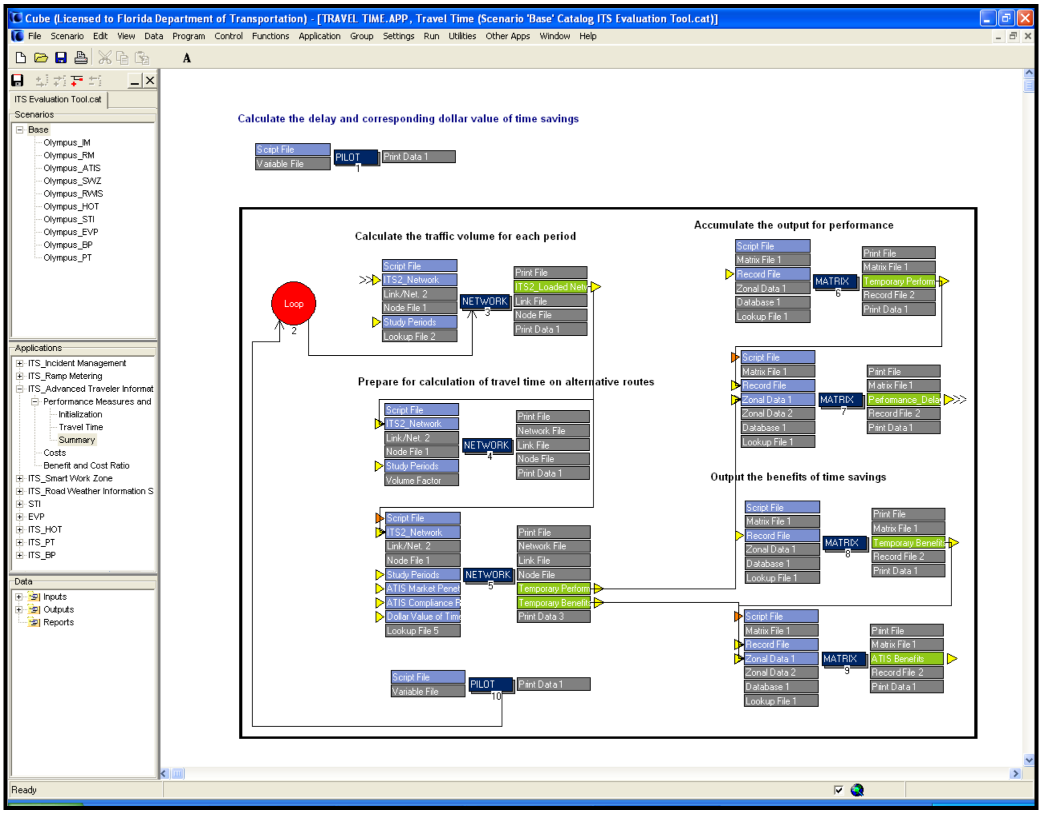


(a)



(b)

Figure 14-3 Modeling Structure for ATIS Evaluation



(c)

Figure 14-3 Modeling Structure for ATIS Evaluation (Continued)

14.6.2 Input Interface

As with the other types of ITS deployments, Figure 14-4 and Figure 14-5 show that the input interface is organized into five groups, as described in Chapter 5. This section presents a discussion of the parameters that are specific to signal control evaluation as follows.

- Impact factors:
  - ATIS market penetration (see Figure 14-1).
  - ATIS compliance rate (see Figure 14-2).
  - Average trip length on the mainline (default = 8 miles).
  - Average trip length on the alternative route (default = 8.2 miles).
  - Percentage of diverted vehicles using freeways (default = 0 percent).
  - Average incident rate for freeways (default = 0.62 per million vehicle-mile).
  - Average incident duration for freeways (default = 43 minutes).
  - Average incident rate for arterials (default = 0.38 per million vehicle-mile).
  - Average incident duration for arterials (default = 23 minutes).

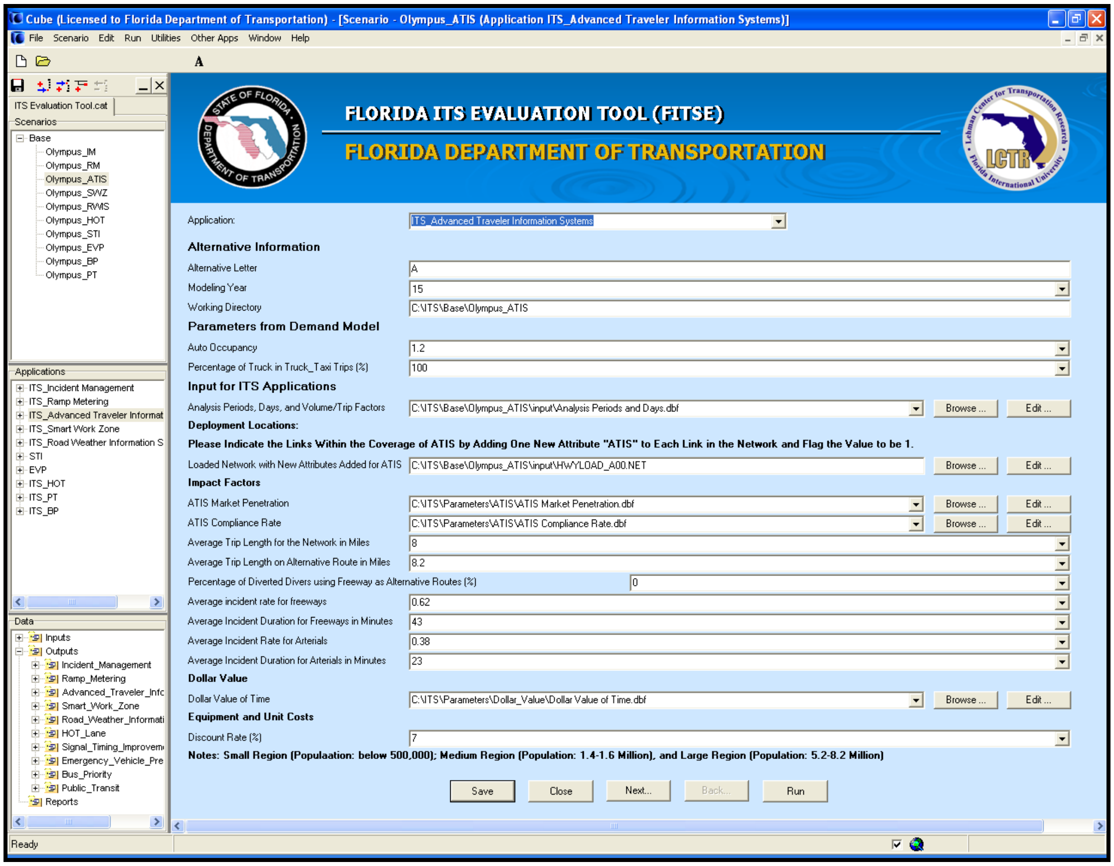


Figure 14-4 User Input for ATIS Evaluation

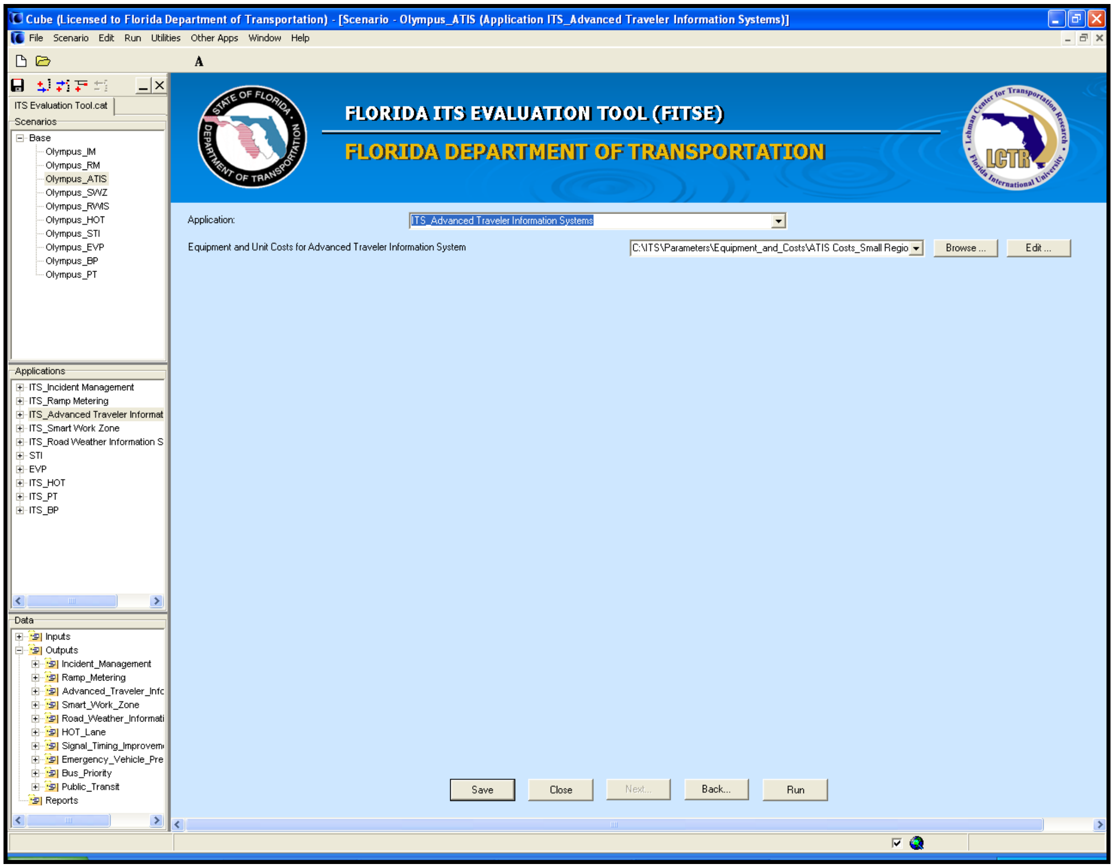


Figure 14-5 Continuation of User Input for ATIS Evaluation

- Equipment and unit costs for ATIS: the costs of ATIS depend on the size of the region. The small region is defined as the area with a population below 500,000, the medium region is the area with a population between 1.4-1.6 million, and the large region is an area with a population is between 5.2-8.2 million.

The user can indicate the links within the coverage of ATIS by adding one new attribute "ATIS" and assign the value of 1 to this attribute (see Figure 14-6). The user may indicate the coverage of ATIS by clicking the covered links and changing the attribute value of "ATIS" to be 1, or using the criteria in the link attribute calculation to modify the attribute value of "ATIS" for a group of links.

Figure 14-7 shows the change of market penetration in percentage with time. The first column is the year, and "%MARKETP" denotes the corresponding percentage of market penetration. Figure 14-8 presents the relationship between the estimated time saving ("TIMESAVED") and the percentage of compliance rate (%COMPLI). The user can modify the default market penetration and compliance rate.

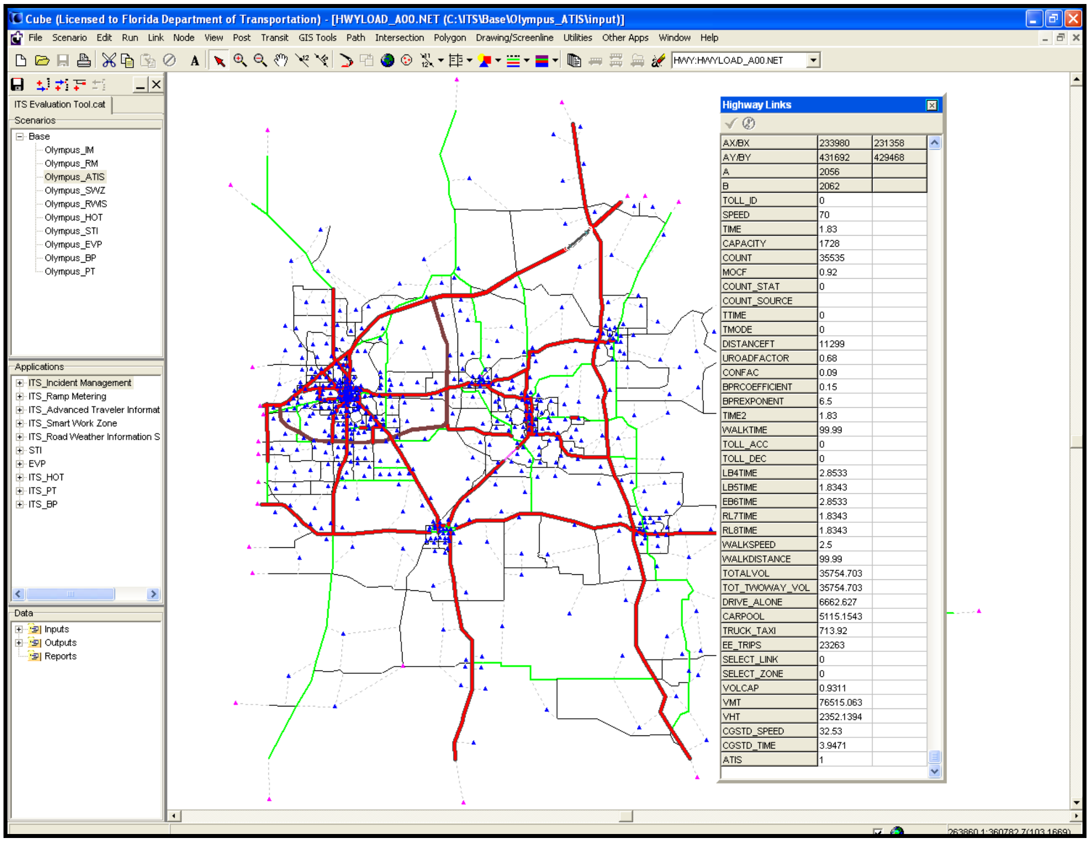


Figure 14-6 Specification of Deployment Location

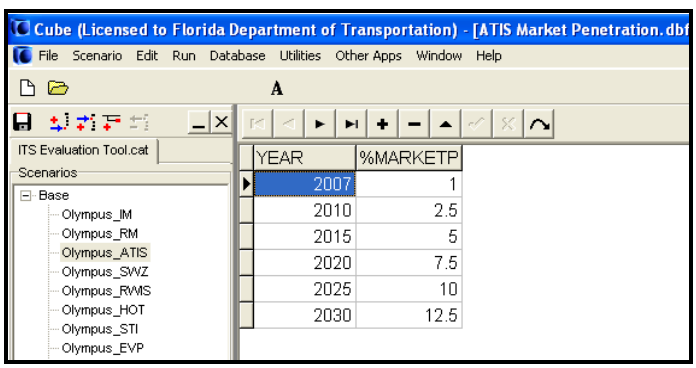


Figure 14-7 Specification of ATIS Market Penetration

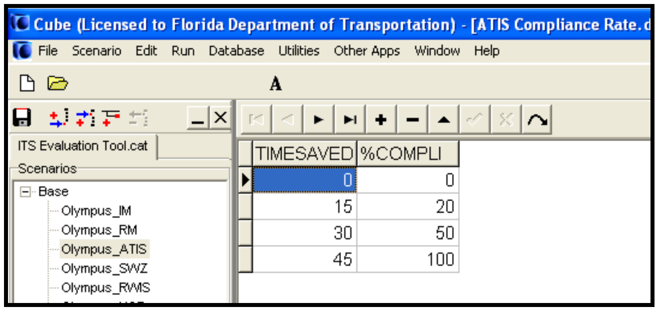


Figure 14-8 Specification of ATIS Compliance Rate

Figure 14-9 shows the input for the equipment and unit costs for ATIS. Three default cost files are provided for ATIS, depending on the size of the region. In the input, "NAME" describes the equipment required, "PER" is units for equipment, and "PER_IN_NUM" is the units expressed as the numeric value for the convenience of calculation. "LIFETIME" indicates the equipment lifetime. "CAPI_COST" and "OM_COST" are the capital costs and operating and maintenance costs, respectively. The column of "SHARE" determines the percentage of total costs spent on this project when sharing some equipment with other ITS applications.

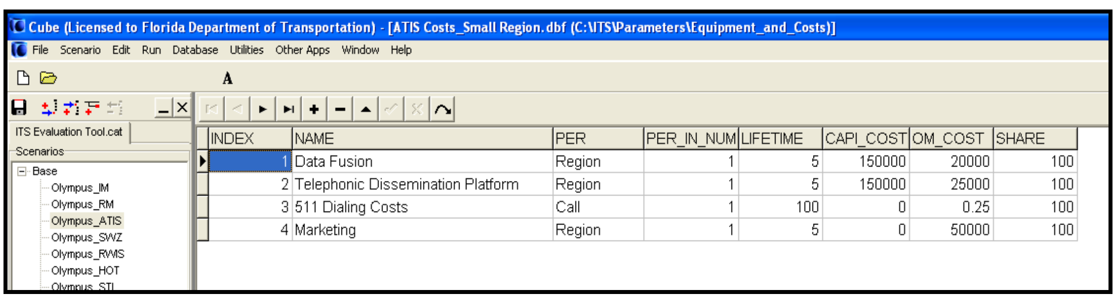


Figure 14-9 Specification of ATIS Compliance Rate

14.6.3 Output Interface

As indicated in Figure 14-10 to Figure 14-12, three standard output files are generated for signal control: 1) performance summary, 2) benefits summary, and 3) benefits and costs summary. These three files are organized under the output category in the data window.

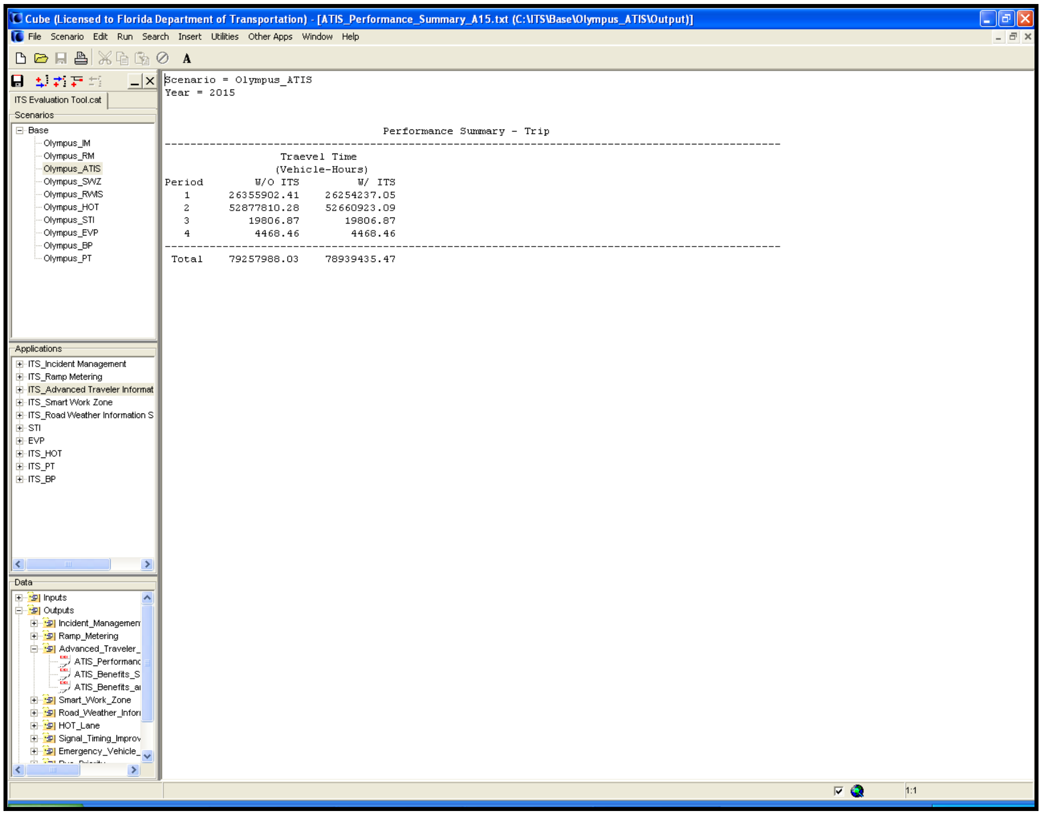


Figure 14-10 Benefit Summary Output for ATIS

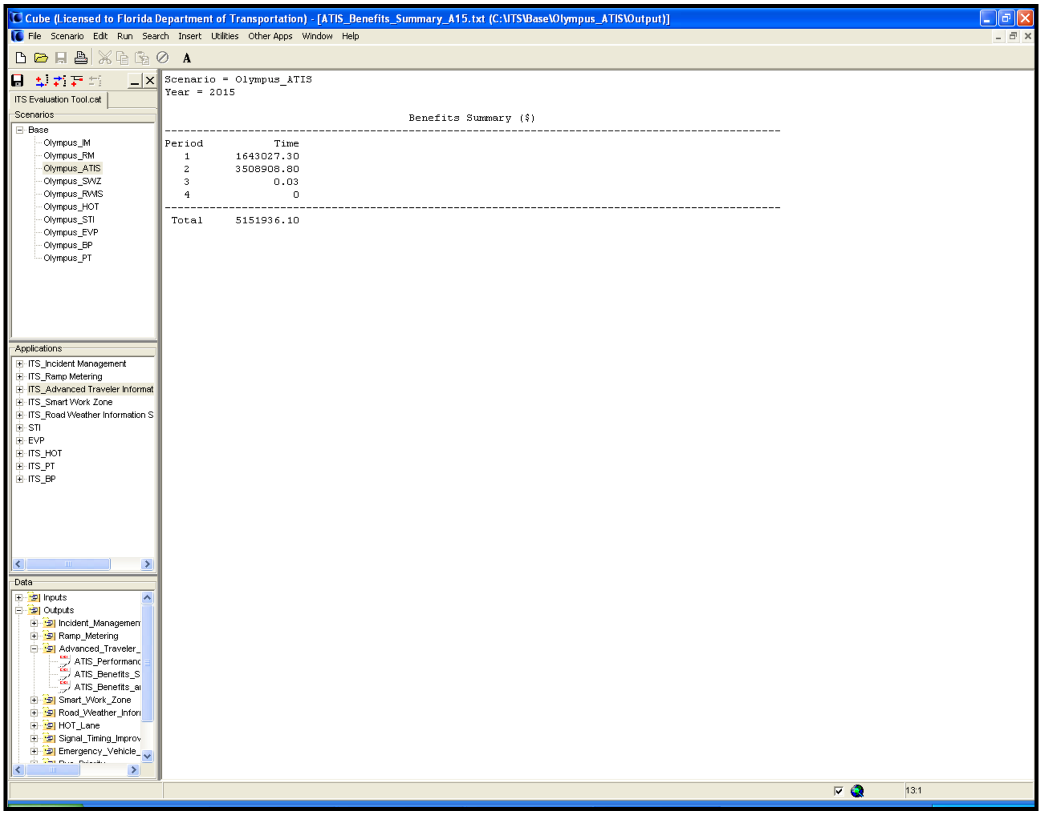


Figure 14-11 Performance Summary Output for ATIS

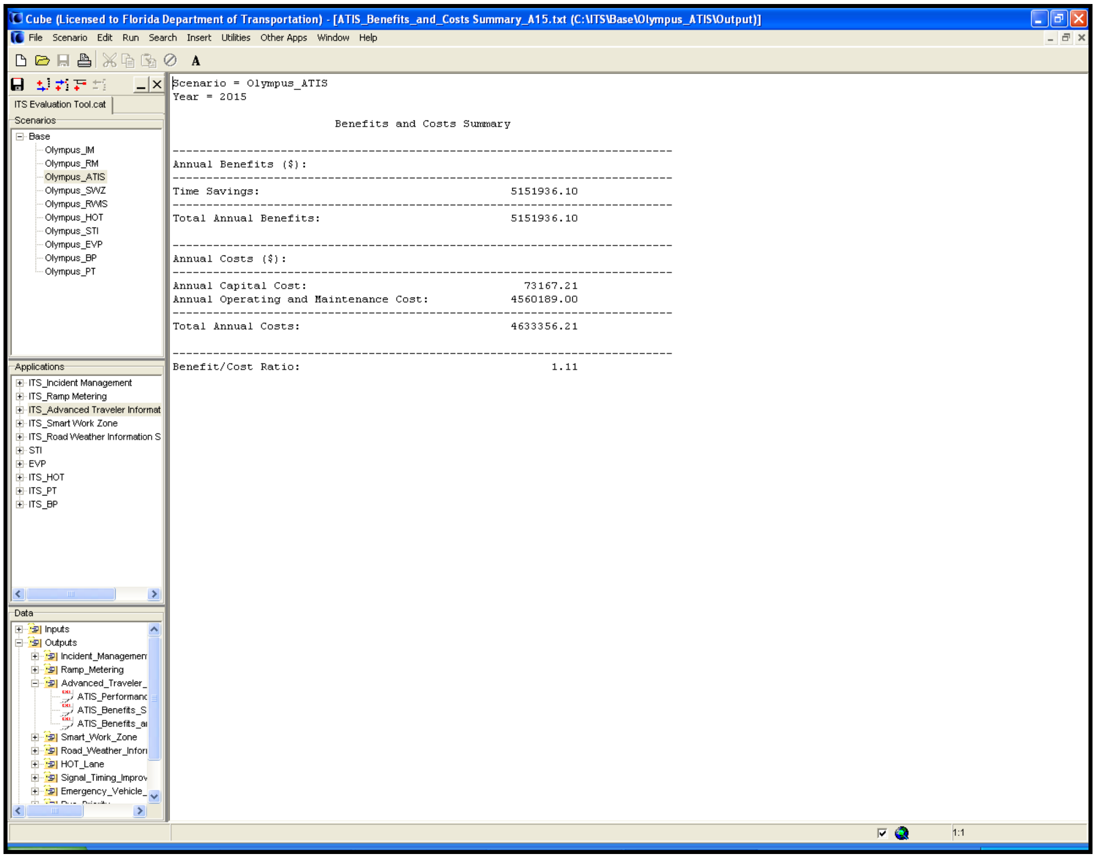


Figure 14-12 Benefit and Cost Summary Output for ATIS

15 Advanced Public Transit System

This chapter discusses the evaluation of Advanced Public Transit Systems, including Automated Scheduling Systems (ATSS), Automated Vehicle Location (AVL) systems, Electronic payment system (EPS), Transit Traveler Information and Security Systems. Bus priority is considered part of arterial management systems in this study and was discussed in Chapter 12.

15.1 Automated Scheduling System and Automated Vehicle Location

15.1.1 Methodology Used in IDAS

IDAS evaluates the benefits and costs of ATSS, AVL, and the combination of ATSS/AVL. Initially, the trip assignment module is run for the base case to obtain the link travel time. The travel time is modified for the specified ATSS and/or AVL deployment by multiplying by the market penetration rate (proportion of transit vehicles that have the technologies) by a reduction factor to account for the benefits of the implemented technologies. The reduction factor is 7 percent for ATSS, 10 percent for AVL, and 15 percent for the combination of ATSS and AVL. Following that, the modal choice, temporal choice, induced/foregone demand, and trip assignment are conducted for both the base case and the improved case with ITS components. The travel time savings for non-transit market sectors are found from the changes in travel time between the base case and the improved case and the savings for transit market sector are evaluated as the difference in passenger-hours, which is defined as the product of transit passenger volume and the saving in transit vehicle travel time between each pair of origins-destinations. The benefits related to the safety, emissions, and fuel consumption are evaluated in the same way as other ITS components.

An additional benefit resulting from the deployment of ATSS and AVL are the reductions in agency capital cost and operational cost. The IDAS default is to assume that the application of ATSS or AVL cause a 1 percent reduction in transit vehicle acquisition cost and 5 percent decrease in average agency operating costs; the combination of these two components results in a reduction of 2 percent in transit vehicle acquisition cost and 8 percent in agency operating costs. To evaluate the transit acquisition cost reduction, IDAS multiplies the total number of transit vehicles by the percentage of vehicles equipped with ATSS or AVL (the market penetration), appropriate reduction rate, and transit vehicle cost. This number is converted into an annual value by considering the useful life of the transit vehicles. Similarly, the reduction in operating costs can be obtained by multiplying the total annual operating cost by the market penetration rate and the corresponding reduction rate. The cost of a bus for a fixed route is assumed to be $225,000 with an average useful life of 12 years. As indicated above, the market penetration rate (number of vehicles equipped with ATSS/AVL) is considered, but the market penetration rate is set as a constant for the whole region and cannot vary by bus line.

15.1.2 Wisconsin Transit AVL

In a Wisconsin Study,[181] data were collected from the Milwaukee County Transit System (MCTS) to determine the benefits of AVL. An AVL system was installed on the entire MCTS fleet, including support vehicles. There was no ATSS component. The system became operational in January 1995. The AVL system improved on-time performance by five to ten percent. The AVL system has also reduced scheduled running times by five to ten percent, but these savings have been used to increase frequency rather than reduce fleet requirements. This study found that buses do not necessarily run faster, but the slight increases in frequency may translate into slight reductions in platform waiting time.

There were 508 buses in active service. Bus purchases averaged between $267,000 and $270,000. The average useful life of transit vehicles was 12 years, per FTA guidelines. No reduction in peak fleet requirements due to AVL was recorded. Street supervisors were reduced by seven positions (25 to 18) through attrition following AVL at an average salary of $55,000 in 2001(excluding fringe benefits). Dispatch staff was increased by approximately three full-time equivalent staff at an average annual salary of $58,000, including a new coordinator position, to accommodate the increase in call traffic. This partially offsets the elimination of the seven street supervisor positions. Given the salary levels reported, this translates into an annual salary savings of $211,000, plus fringe benefits of 63 percent or $133,000 for a total savings of $344,000.

15.1.3 Representation of Transit ITS in Network Based Travel Model Study

A study initiated by the U.S. DOT titled "Representation of Transit ITS in Network Based Travel Models study[182]" reviewed previous evaluations of APTS technologies and provided recommendations regarding the evaluation of the benefits of APTS, as they relate to travel demand models. Previous studies in Denver and Milwaukee attributed a 5 percent increases in ridership to AVL. Toronto established a more conservative estimate, however, implying that AVL would only result in a 0.5 to 1 percent increase in ridership. Previous studies also showed that using information

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[181] "Development of Methods for Benefits Assessment of ITS Deployment in Wisconsin," Cambridge Systematics Inc., Final Report No. 0092-02-16, July 2004

[182] Smith, S.B. and K. Gay, "Representation of Transit ITS in Network Based Travel Models," U.S. Department of Transportation Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center, Cambridge, MA, March 2005.

from AVL to adjust schedules might enable a reduction of 2 to 5 percent in fleet size and a cost reduction of 4 to 9 percent. Other mentioned benefits include a reduction in travel time on some routes by 10 percent based on AVL data resulting in cutting 7 buses out of the total of 200 buses.

NCHRP Report 431[183] presented results from a stated preference survey of several thousand motorists along a corridor in California. They found that travelers value one minute of uncertainty in travel time (as measured by standard deviation of travl time) as two or three minutes of in-vehicle travel time. The US DOT study used the above findings to estimate that travelers might value a 10 percent improvement in on-time performance (e.g., from 80 to 88 percent) as highly as a 1 to 3 minute improvement in in-vehicle time.

15.1.4 ITS Transit Fact Sheets

The ITS Transit Fact Sheets[184] were developed as a web resource to provide transit agencies with basic information about advanced technologies used in transit system planning, operations, maintenance, and communications.

The information in the fact sheets were developed through a cooperative effort of the Federal Transit Administration (FTA), the U.S. Department of Transportation’s John A. Volpe National Transportation Systems Center, and the ITS America Public Transportation Forum. The fact sheets include useful information regarding the benefits and costs of APTS technologies. However, the web site is currently not complete and does not include information about all APTS applications.

The summary presented in the fact sheets indicates that the use of AVL improves the on-time performance by 9 to 23 percent in large metropolitan cities. Successful AVL and CAD implementations can reduce fleet size by 2 to 5 percent. It was reported that the Baltimore’s Maryland Transit Administration (MTA) reduced its fleet size to meet the same level of service, resulting in savings of $2-$3 million per year. The Kansas City Area Transportation Authority (KCATA) saved $1.6 million with its fleet reductions resulting from AVL-CAD implementation.

15.1.5 Assessment

There are two main benefits to AVL/ATSS:

- Improvement in on-time performance, which results in reduction in wait time and travel time variability.

[183] Small, K. et al., “Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User Cost Estimation,” NCHRP Report 431, National Academy Press, Washington DC, 1999.

[184] http://www.pcb.its.dot.gov/factsheets/factsheets.asp

- Increase in productivity, which results in a decrease in the required number of buses or the required staff.

Regarding the first benefit, Table 15-1 indicates that the implementation of AVL has resulted in a 5 to 10 percent improvement in on-time performance and when combined with ATSS has resulted in a 23 percent improvement.

Table 15-1 On-time Performance Improvements due to AVL and ATSS

Location	Fleet Size	On-time performance
Wisconsin	508	5-10%
Kansas	200	7%
Baltimore	850	23%
City of Racine	-	23%

The implementation of AVL/ATSS and other APTS evaluation should consider the following when evaluating ITS:

- APTS deployment will have to be associated with transit mode lines rather than implemented on the origin-destination level, as is done in IDAS.
- Market penetration for each type of APTS deployment will have to be considered at the transit line level rather than at the regional level, as is done in IDAS.
- The capital cost and operating cost reduction should be based on the actual vehicle-mile travel of transit vehicles per line rather based on the total fleet, as is done in IDAS.
- Revenue increase should be based on the actual shift in travelers to transit rather than percentage reduction.

15.2 Transit Security Systems

15.2.1 IDAS Methodology

The ridership increases due to transit security is assumed to be zero percentage because it is argued that there is no benefit data available to support this increase. The benefit considered by IDAS due to the transit security systems is the reduction of the fatalities resulting from the reduced incident response time, which includes two parts: the reduction in fatalities on transit vehicles and the reduction in fatalities at transit related facilities such as stops, stations, parking areas, and so on. Since the method assumes that the reduced fatalities become injuries instead, the total savings are obtained by multiplying the estimated number of reduced fatality by the difference between the fatality cost and the injury cost. A 10 percent reduction in fatalities both for the transit vehicles and the transit-related facilities is used in IDAS, based on the study results in Denver and Kansas City.

15.2.2 Other Evaluations

The USDOT review mentioned in Section 15.1.3 above indicated that the Southeastern Pennsylvania Transportation Authority (SEPTA) equipped four of its buses with a surveillance and monitoring system using digital video. This resulted in a 32 percent reduction in claims and a $15 million decrease in annual payouts.

In Denver, the assaults on bus operators and passengers were reported to have dropped by 20 percent after the Denver Regional Transit District (RTD) implemented its AVL/CAD system, which contained a silent alarm and covert microphone feature.[185]

15.2.3 Assessment

Based on the above, the security system benefits are derived from three effects:

- Reduction in fatalities due to the reduction in response time. A 10 percent reduction can be assumed similar to IDAS. However, the fatality rate expressed in fatality per bus per year is needed, as an input in the analysis.
- Reduction in insurance claims. A reduction of 20 percent in insurance claims can be assumed. However, the claim rate expressed in claim per bus per year is needed, as an input in the analysis.
- Reduction in crimes, which potentially results in increase ridership. A default of 1 percent increase in ridership can be assumed. However, the crime rate must be expressed in fatality per bus per year as input for the analysis.

[185] Smith, S.B. and K. Gay, “Representation of Transit ITS in Network Based Travel Models,” U.S. Department of Transportation Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center, Cambridge, MA, March 2005.

15.3 Transit Traveler Information Systems

15.3.1 Methodology Used in IDAS

IDAS considers two types of transit traveler information: kiosk and DMS. The user has to identify the zone centroids where DMS and kiosks will be installed and select the affected transit market sectors. IDAS assumes that the main impact is the savings in travel time. For each affected zone from which the trips depart, the number of originating trips is multiplied by the percentage of travelers who look at the message sign, the percent that travelers benefit from the information, and the actual saved time. The obtained figure is then monetized by three times the normal value of travel time (since this saving is considered to be related to travel time reliability rather than recurring travel time). The followings are the used default values:

- The percentage of travelers who at look at the information (50 percent for DMS and 5 percent for kiosks).
- The travelers who benefit from the messages (20 percent).
- The average saved out-of-vehicle time (2 minutes with a monetary value per passenger).

15.3.2 Representation of Transit ITS in Network Based Travel Models Study

The "Representation of Transit ITS in Network Based Travel Models" study[186] indicates that the benefits from transit ATIS information could increase traveler satisfaction. A survey of passengers using the London Transport's COUNTDOWN system indicated a valuation of the system between $0.35 and $0.40. If the value of in-vehicle travel time (IVTT) is assumed to be $7 or $8 per hour, this valuation corresponds to approximately 3 minutes of IVTT. The study mentioned that real-time information might enable more effective trip selection through the transit system. For example, in Seattle, WA, a survey conducted on SmarTraveler users indicated that, based on improved information, 5 to 10 percent would change modes.

In addition to reducing the disutility of wait time as described above, the study performed an analysis to determine the benefits of transit traveler information systems in reducing travel time waiting. As shown in

[186] Smith, S.B. and K. Gay, "Representation of Transit ITS in Network Based Travel Models," U.S. Department of Transportation Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center, Cambridge, MA, March 2005.

Table 15-2 the saving in waiting time due to real time information is expected to range between 1 and 2 minutes compared to static information depending on the bus headway and the accuracy of information.

Table 15-2 Expected Wait Time for Various Headways (Minutes)

Headway	1. Random Traveler Arrivals	2. Schedule information only	3. Low accuracy real-time information	4. High accuracy real-time information
6	3.29	3.11	2.52	2
8	4.22	3.4	2.7	2
10	5.18	3.54	2.81	2
12	6.15	3.62	2.953	2
15	7.62	3.73	3	2
20	10.1	3.91	3	2
30	15.1	4	3	2

This study also indicated that the 1 to 3 percent ridership increase can be assumed in the benefits assessment, provided, that any real-time information supplied is accurate enough to reduce waiting times. This is a smaller ridership impact than would be expected with a new service (such as a new express bus route), but it is still considered significant.

15.3.3 Assessment

It appears that transit ATIS can result in two types of user benefits: a more acceptable waiting time due to being more informed about their trips and a reduction in their wait time due to being informed of the arrival of the transit vehicle. The first benefit can be achieved by implementing DMS at terminals and bus stops as well as by using hand-held devices. The second can be achieved with pre-trip information devices

The analysis presented in Section 15.3.2 indicates that the first benefit can be approximated by a reduction of 3 to 5 minutes in travel time and the second benefit estimate is a reduction between a 1 and 2 minutes of waiting time.

15.4 Electronic Transit Fare Payment System

15.4.1 Methodology used in IDAS

In IDAS, the application of Electronic Transit Fare Payment Systems is assumed to cause a shift in ridership from the non-transit market sector (excluding the truck) to the transit market sector. A default value of a 3 percent ridership increase is used in IDAS. The resulting shift in ridership is applied to the trip matrix that is used in the assignment. The results from the assignment are then used for the evaluation of travel time savings, travel time reliability improvement, safety, environment, and energy benefits. Moreover, the transit agency is assumed to benefit from the implementation of Electronic Transit Fare Payment Systems due to the reduction in fare evasion, cash handling errors, and labor costs. The corresponding benefit is 14 percent of the bus and rail revenues, obtained by adjusting the original revenues with the given market penetration.

15.4.2 Representation of Transit ITS in Network Based Travel Models Study

Even though Transit ITS Impacts Matrix reports that one transit operator (Chicago Transit Authority) estimates a 2 to 5 percent increase due to electronic fare payment, the actual increase in ridership is heavily dependent on both existing fare collection practices at the operator in question and on whether the introduction of electronic fare payment is also accompanied by a change in fare policies.

15.4.3 Assessment

In this study, a 3 percent mode shift will be assumed. This will be achieved in the regional demand model by utilizing a similar method to that described above to obtain the mode shift in the case of AVL/ATSS.

15.5 Requirement Analysis

Below are the identified requirements for the evaluation of Advanced Public Transit Systems (APTS):

- The Tool shall be able to evaluate APTS implementations including Automated Scheduling Systems (ATSS) and Automated Vehicle Location (AVL) systems, Electronic Payment System (EPS), Transit Traveler Information, and Security Systems.
- The APTS deployment shall be evaluated at the transit mode line level, rather than implemented on the origin-destination level, as is done in IDAS.
- The user shall be able to select the percent of transit vehicles of each transit line that has a given type of technology (market penetration of technology).
    - The market penetration for each type of APTS deployment shall be considered at the transit line level rather than at the regional level, as is done in IDAS.
- The Tool shall calculate the mobility improvements due to APTS.
- The Toll shall consider any safety improvement due to APTS.
- The Tool shall be able to estimate the increase ridership due to APTS.

- The Tool shall calculate the capital cost and operating cost reduction due to APTS:
    - The capital cost and operating cost reduction shall be based on the actual vehicle-mile travel of transit vehicles per line rather than based on the total fleet, as is done in IDAS.
- The Toll shall calculate the revenue increase due to APTS:
    - Revenue increase shall be based on the actual shift in travelers to transit, rather than percentage reduction, as is done in IDAS.

15.6 Methodology

APTS improvements include mobility, security (reduction in fatalities and injuries), increase in revenue, and reduction in agency cost. Figure 15-1 presents an overview of the methodology. The methodology can be implemented based on daily demand or TOD period demand. Below is a description of the estimation of each of these deployments.

From the methodological point of view, there are two main categories of evaluated ITS deployments. The first is considered to be transit line-based (since the user has to define the lines with these implementations). This category includes Automatic Vehicle Location (AVL), Automatic Transit Scheduling System (ATSS), AVL/ATSS, and Transit Security System (TSS). The second category is based on all lines in the network but the calculated benefits are multiplied by a certain percentage to reflect the market penetration of the technology. These include Transit Information System (TIS) and Electronic Fare Collection System (EFC).

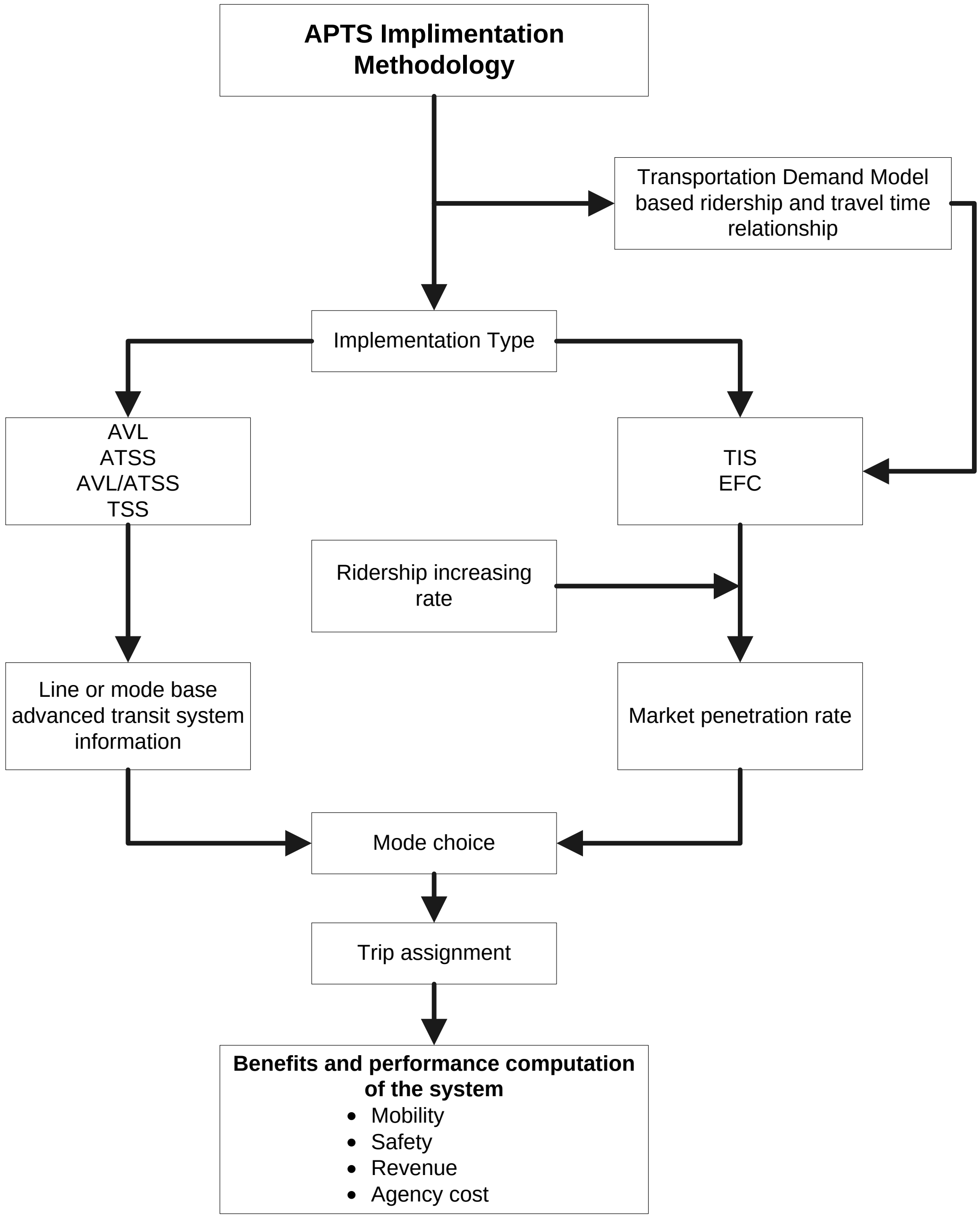


Figure 15-1 APTS Evaluation Methodology

15.6.1 Mobility Benefits

Many of APTS implementation affect the transit system on time performance and schedule running time/adherence that cause a reduction on waiting and transfer time. In addition, some APTS applications also increase ridership due to factors other than travel time effects such as the reduction in crime in the case of transit security systems, increase in payment convenience in the case of electronic fare payment systems, and increase in traveler comfort in the case of transit information systems. Eventually, both of the two effects above will result in shifting demand from the highway network to the transit network. The regional mode split model is used to estimate these shifts. However, as described later in this section, this will require deriving relationships that convert previously observed shifts in demand due to factors other than travel time savings to equivalent travel time savings (travel time savings that would result in the same shifts in demands). Once the regional modal split model is used to estimate the O-D matrix split, the regionally calibrated assignment procedure can be used to estimate the demand in the network allowing the estimation of the network mobility performance with and without APTS.

To identify an equivalency between mode shift due to non-travel time savings and travel time savings, ridership, and travel time relationship were derived based on the calibrated demand model. These relationships are shown in Figures 15-2, 15-3, and 15-4 for the peak period, off-peak period, and daily traffic based on the OlympusPT Model. They should be derived for locally calibrated regional models when this method is implemented. Previously estimated mode shifts due to non-travel time savings are:

- AVL increased the ridership 5 percent in Denver and Milwaukee and 0.5-1 percent in Toronto.
- Transit information system increased ridership 1 to 3 percent. A default value of 3 percent for ridership increase is used in IDAS.
- Electronic transit fare system increased the ridership 2 to 5 percent (Chicago transit Authority).
- Transit security system increased the ridership 1 percent.

Figure 15-2 to Figure 15-4 can then be used to convert the shifts observed above to travel time savings for use in the modal split.

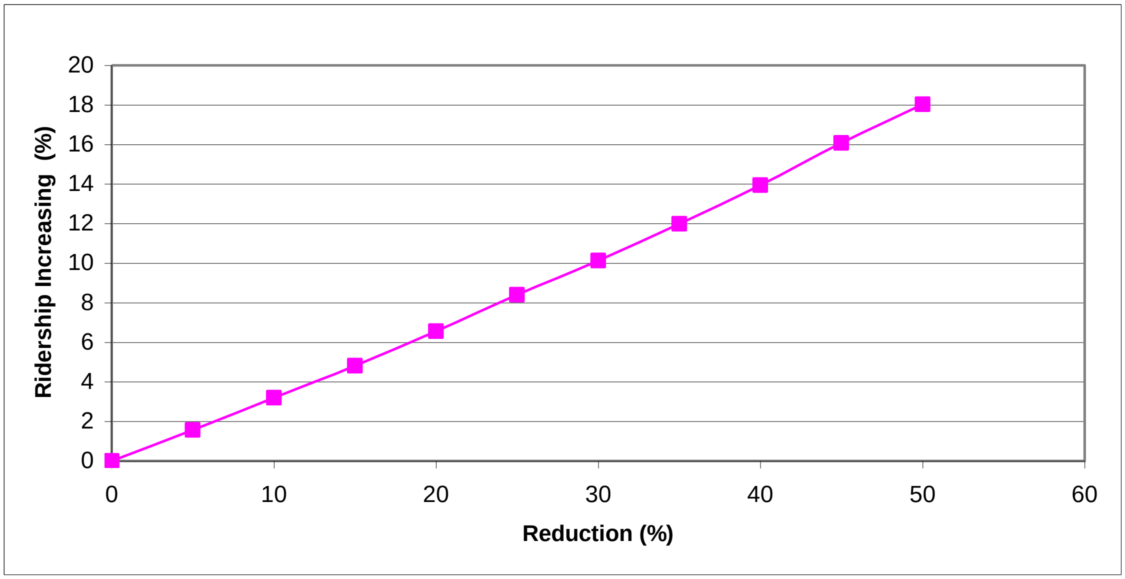


Figure 15-2 Olympus PT Model Travel Time Reduction Rate and Ridership Increasing Rate Relationship (Peak Period)

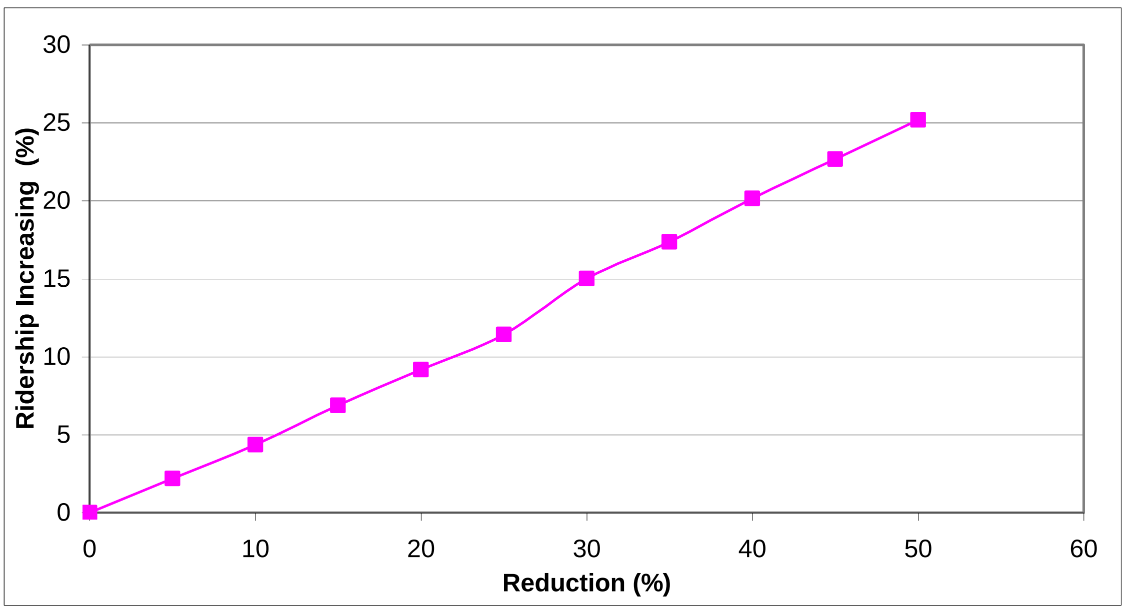


Figure 15-3 Olympus PT Model Travel Time Reduction Rate and Ridership Increasing Rate Relationship (Off-Peak Period)

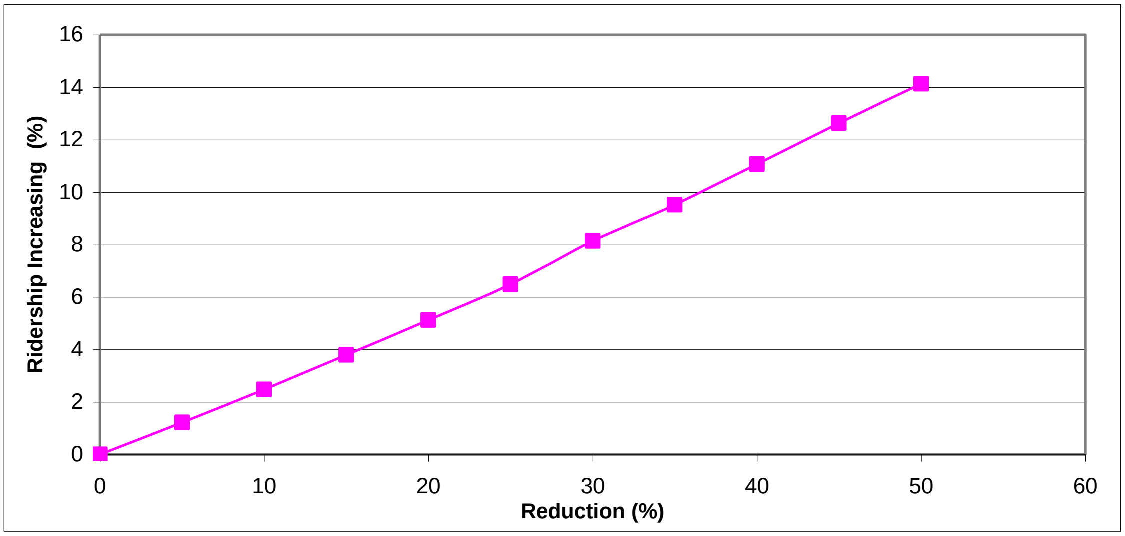


Figure 15-4 Olympus PT Model Travel Time Reduction Rate and Ridership Increasing Rate Relationship (Daily)

After rerunning the model, the Tool calculates the performance measurements of the system and the benefit cost for bus priority implementation.

15.6.2 Safety

The safety impacts of APTS are calculated as follows:

- 10 percent reduction in fatality is assumed due to security system. The number of fatality per bus per year was obtained from FTIS data base (default table as given below).

Table 15-3 Transit System Accident Rate

Accident Type	Cost ($ per accident)	Accident rate per PMTx10^6
Fatality	3.000.000	1
Injury	75.000	100

- The reductions in the number of fatalities, injuries and PDO on the highway are calculated based on the reduction in the highway traffic resulting from the mode shift.

15.6.3 Agency Cost Reduction

The agency cost reduction is calculated based on the estimated reduction in the required number of buses ($F_{AVL/ATSS}$) as follows:

$$\text{Eliminated Vehicle} = \frac{\text{Total Equippped transit VMT}}{\text{Total transit VMT}} * \mathrm{F}_{\mathrm{AVL/ATSS}} \tag{15-1}$$

where

$$F_{AVL/ATSS} = \begin{bmatrix} AVL = 1\% \\ ATSS = 1\% \\ AVL + ATSS = 2\% \end{bmatrix}$$

$$\text{Eliminated Vehicle Benefit} = \frac{\text{Eliminated Vehicle} * \text{Vehicle Cost}}{\text{Useful Life of Transit Vehicle}} \tag{15-2}$$

Similarly, the agency operation cost reduction is calculated as follows:

$$\mathrm{A}OCR = \frac{\text{Total Equippped transit VMT}}{\text{Total transit VMT}} * F_{AOCR} * \text{Total Operating Cost} \tag{15-3}$$

where

$$F_{AOCR} = \begin{bmatrix} AVL = 5\% \\ ATSS = 5\% \\ AVL + ATSS = 8\% \end{bmatrix}$$

15.6.4 Increase in Agency Revenue

The increase in agency revenue consists of two elements:

- Revenue increases due to electronic fare collection. A default of 6 percent is assumed due to reduction in fare evasion and fraud.
- Revenue increases due to an increase in ridership. This is calculated by multiplying an average fare by the total number of travelers shifted to transit.

15.7 Cost

The following costs are estimated based on the Florida Specific ITS Benefit and Cost Parameter project recommendations and other studies:

Transit Management Center: This includes the capitol cost for a central facility, hardware, software, integration, labor costs, and operation and maintenance. No good estimates are currently available for these values, but IDAS assumes $800,000 to $1,700,000 as the central software cost. In this study, the Transit Management Center hardware, software, and facility cost is assumed to be $1,500,000 and O&M to be $300,000. However, it should be emphasize that these are only rough estimates and the user should change the defaults if better values are available.

AVL and ATSS: The cost is estimated to be $8,000 per vehicle for AVL. No additional dispatcher is assumed but a data analyst will need to be hired at an average fully loaded cost of $75,000 per year. In each vehicle, there it is assumed that Mobile Data Terminal (MDT) Integrated with Communication will be installed costing $5,000. An Automatic Passenger Counting (APC) cost is estimated at $10,000. The maintenance cost is assumed to be 5 percent of the equipment cost.

Security: The cost is estimated at $8,000 to $12,000 per bus. CCTV implementation at remote locations is estimated to cost $15,000 to $25,000 per unit.

Transit Electronic Payment Systems: The cost is estimated at $11,000 to $13,000 per bus.

Transit Information Systems: The on-board devices of these systems include on−board text messaging signs with an estimated cost of $15,000 and bus station dynamic message signs with an estimated cost of $20,000.

15.8 Implementation

The evaluation methodology presented in the previous section is implemented in the FSUTMS/Olympus model, using the script language of the Cube software. As with other ITS applications, APTS can be selected from a pull-down menu.

15.8.1 Modeling structure

For the transit system, the modeling structure consists of a matrix and highway network preparation, transit system path, skim tables preparation, mode choice, assignment, performance summary, and benefits and cost modules, as shown in Figure 15-5. For detailed implementation procedures, users are referred to the catalog in Cube software.

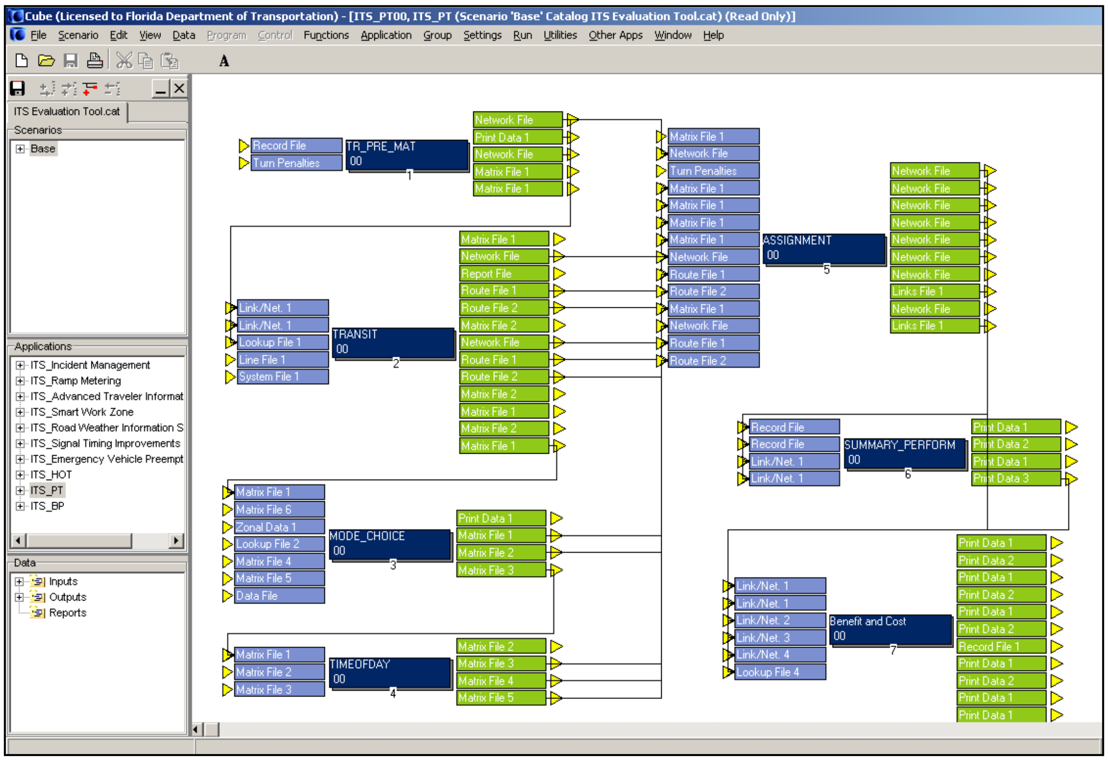
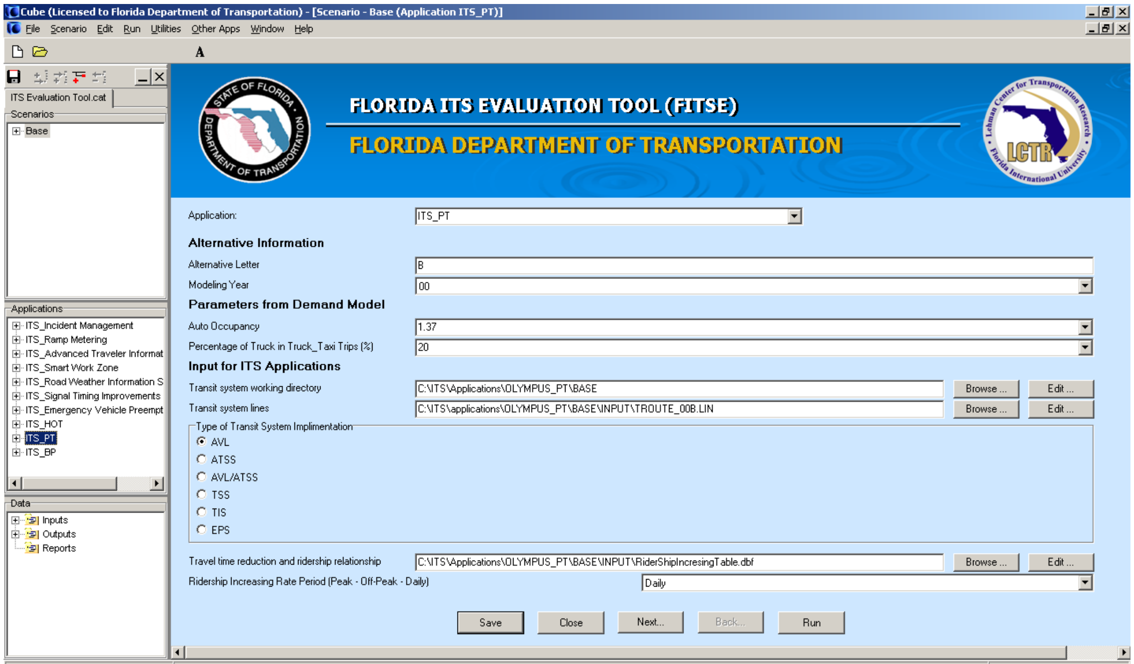


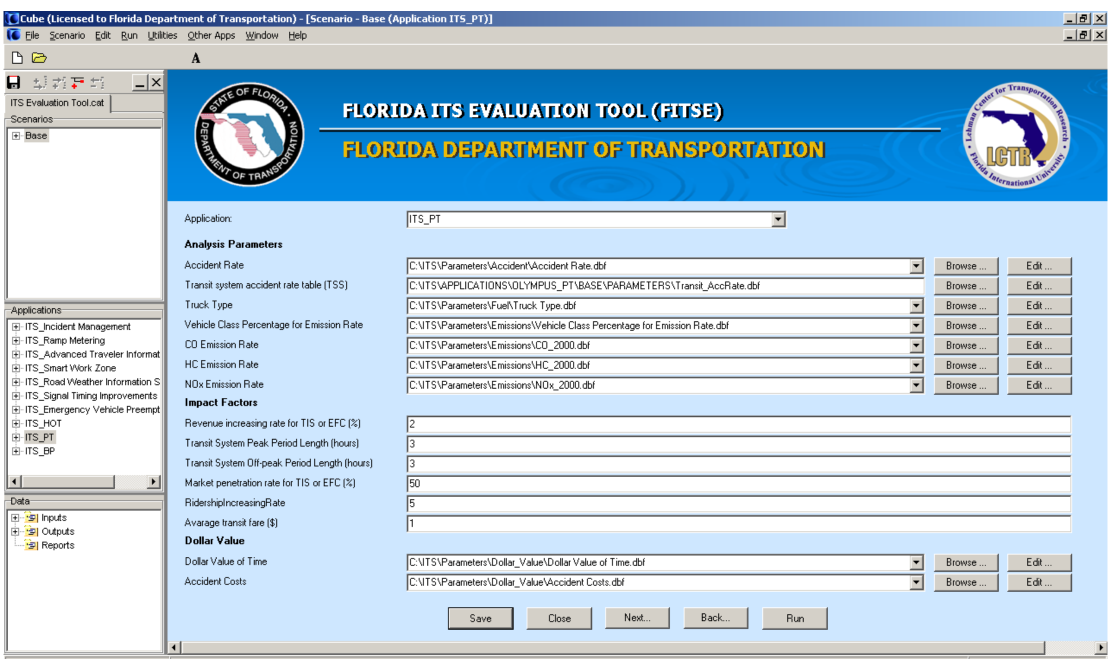
Figure 15-5 Modeling Structure for APTS

15.8.2 Input Interface

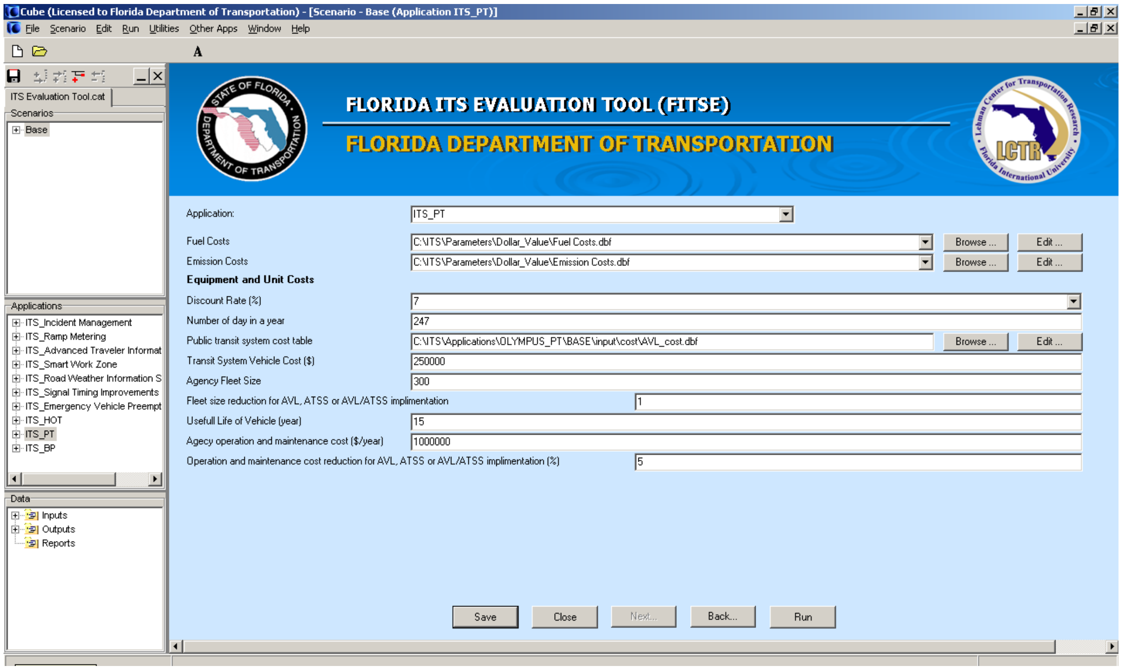
Figure 15-6 shows that, as with other ITS deployments, the inputs are organized into five groups (refer to Chapter 5 for details). A description of the parameters that are specific to EVP evaluation is given in this section.



(a)



(b)



(c)

Figure 15-6 User Input Interface for APT (Continued)

- Location of Transit System Lines.
- Types of Transit System Implementation (AVL, ATSS, AVL/ATSS, TSS, EFC, TIS).
- Travel time reduction and ridership relationship.
- Ridership increasing rate period (peak, off-peak or daily).
  - Analysis periods, hours and days in each period.
- Volume factors to convert the daily volume to volume in each period.

Default values are provided, however, users are encouraged to modify these default values based on local conditions.

- Impact factors
  - Revenue increasing rate for TIS or EFC (2 percent).
  - Transit system peak period length (3 hours).
  - Transit system off-peak period length (3 hours).
  - Market penetration rate for TIS or EFC (50 percent).
  - Ridership increasing rate (5 percent).
  - Public transit system cost table.

Other default parameters include:

- Transit system vehicle cost ($250,000).
- Agency fleet size (300 buses).
- Fleet size reduction for AVL, ATSS or AVL/ATSS (1 percent).

- Useful life of vehicle (15 years).
- Agency operation and maintenance cost ($1,000,000/year).
- Agency operation and maintenance cost reduction for AVL, ATSS or AVL/ATSS (5 percent).

In the model, ITS equipped transit lines need to be defined for AVL, ATSS, AVL/ATSS, and TSS but not for EFC and TIS, as described in the methodology section. Current implementation of the tool it is assumed that EFC and TIS are implemented on regional bases. This can be done using a text input file for modeling or the Cube GUI. To define a line as an ITS equipped line, the user convert the mode number to an APTS implemented mode number by adding 30 existing mode number, as shown in Figure 15-7. For example, if the existing mode number is 31, then we need to change the number to 61 to specify APTS equipped line. The use of the GUI option is shown in
Figure 15-8.

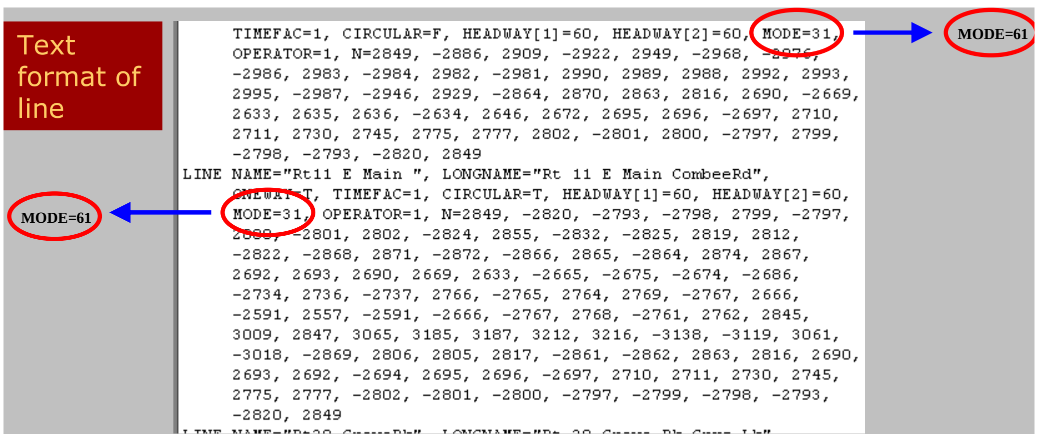


Figure 15-7 Text File Editing to Specify APTS Equipped Lines

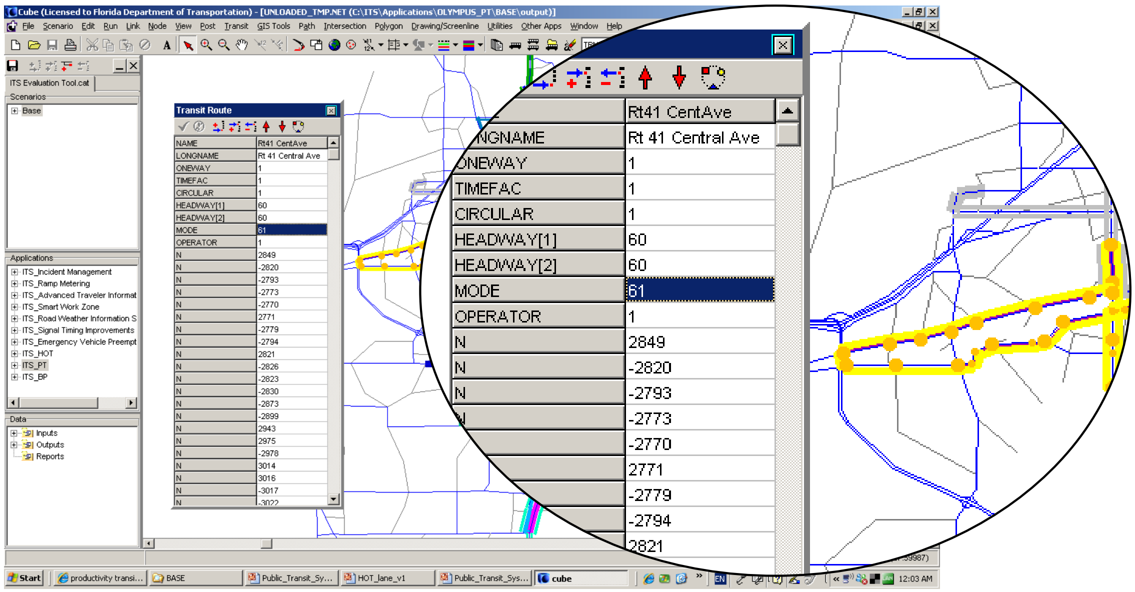
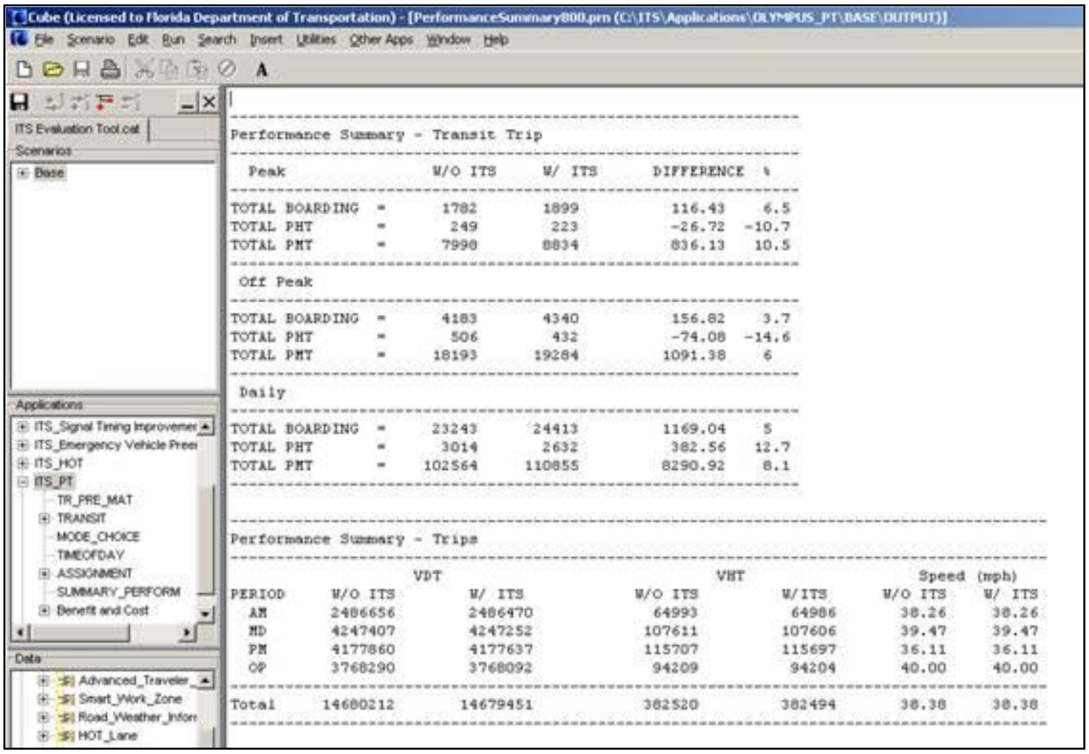


Figure 15-8 GUI Specification of APTS Line

15.8.3 Output Interface

As indicated in Figure 15-9 to Figure 15-11, three standard output files are generated for signal control: 1) performance summary, 2) benefits summary, and 3) benefits and costs summary. These three files are organized under the output category in the data window.



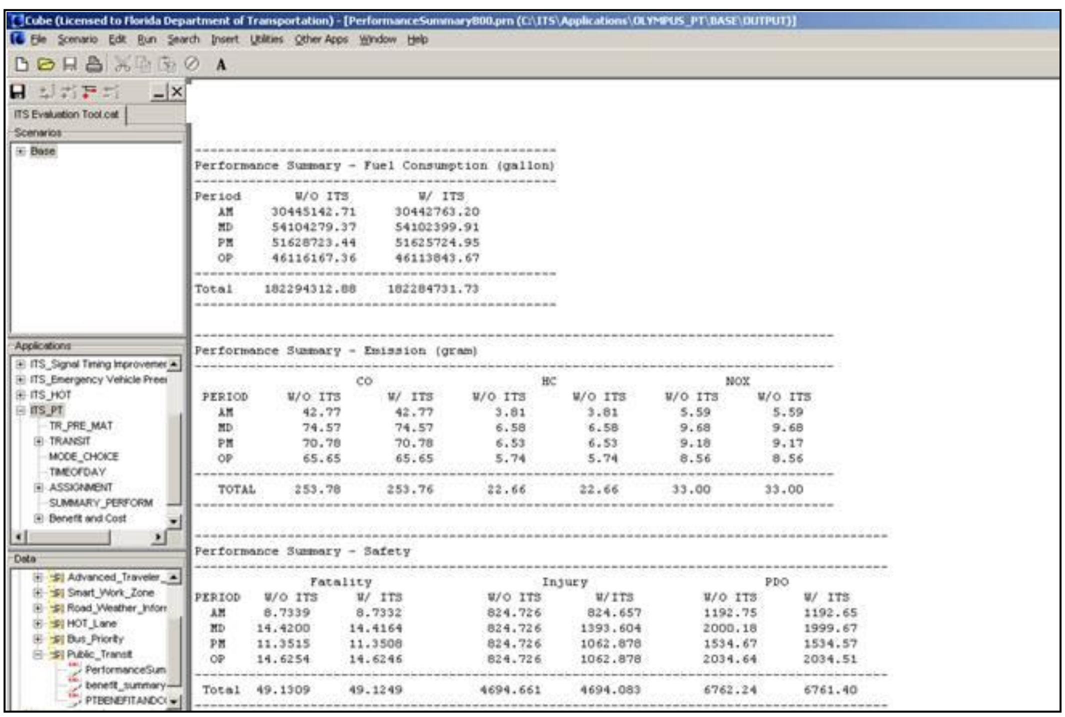
Performance Summary - Transit Trip

Peak		W/O ITS	W/ ITS	DIFFERENCE	%
TOTAL BOARDING	=	1782	1899	116.43	6.5
TOTAL PHT	=	249	223	-26.72	-10.7
TOTAL PMT	=	7998	8834	836.13	10.5
Off Peak					
TOTAL BOARDING	=	4183	4340	156.82	3.7
TOTAL PHT	=	506	432	-74.08	-14.6
TOTAL PMT	=	18193	19284	1091.38	6
Daily					
TOTAL BOARDING	=	23243	24413	1169.04	5
TOTAL PHT	=	3014	2632	382.56	12.7
TOTAL PMT	=	102564	110855	8290.92	8.1

Performance Summary - Trips

	VDT		VHT		Speed (mph)	
PERIOD	W/O ITS	W/ ITS	W/O ITS	W/ITS	W/O ITS	W/ ITS
AM	2486656	2486470	64993	64986	38.26	38.26
MD	4247407	4247252	107611	107606	39.47	39.47
PM	4177860	4177637	115707	115697	36.11	36.11
OP	3768290	3768092	94209	94204	40.00	40.00
Total	14680212	14679451	382520	382494	38.38	38.38

(a)



Performance Summary - Fuel Consumption (gallon)

Period	W/O ITS	W/ ITS
AM	30445142.71	30442763.20
MD	54104279.37	54102399.91
PM	51628723.44	51625724.95
OP	46116167.36	46113843.67
Total	182294312.88	182284731.73

Performance Summary - Emission (gram)

	CO		HC		NOX	
PERIOD	W/O ITS	W/ ITS	W/O ITS	W/O ITS	W/O ITS	W/O ITS
AM	42.77	42.77	3.81	3.81	5.59	5.59
MD	74.57	74.57	6.58	6.58	9.68	9.68
PM	70.78	70.78	6.53	6.53	9.18	9.17
OP	65.65	65.65	5.74	5.74	8.56	8.56
TOTAL	253.78	253.76	22.66	22.66	33.00	33.00

Performance Summary - Safety

	Fatality		Injury		PDO	
PERIOD	W/O ITS	W/ ITS	W/O ITS	W/ITS	W/O ITS	W/ ITS
AM	8.7339	8.7332	824.726	824.657	1192.75	1192.65
MD	14.4200	14.4164	824.726	1393.604	2000.18	1999.67
PM	11.3515	11.3508	824.726	1062.878	1534.67	1534.57
OP	14.6254	14.6246	824.726	1062.878	2034.64	2034.51
Total	49.1309	49.1249	4694.661	4694.083	6762.24	6761.40

(b)

Figure 15-9 Performance Summary Output File for APTS

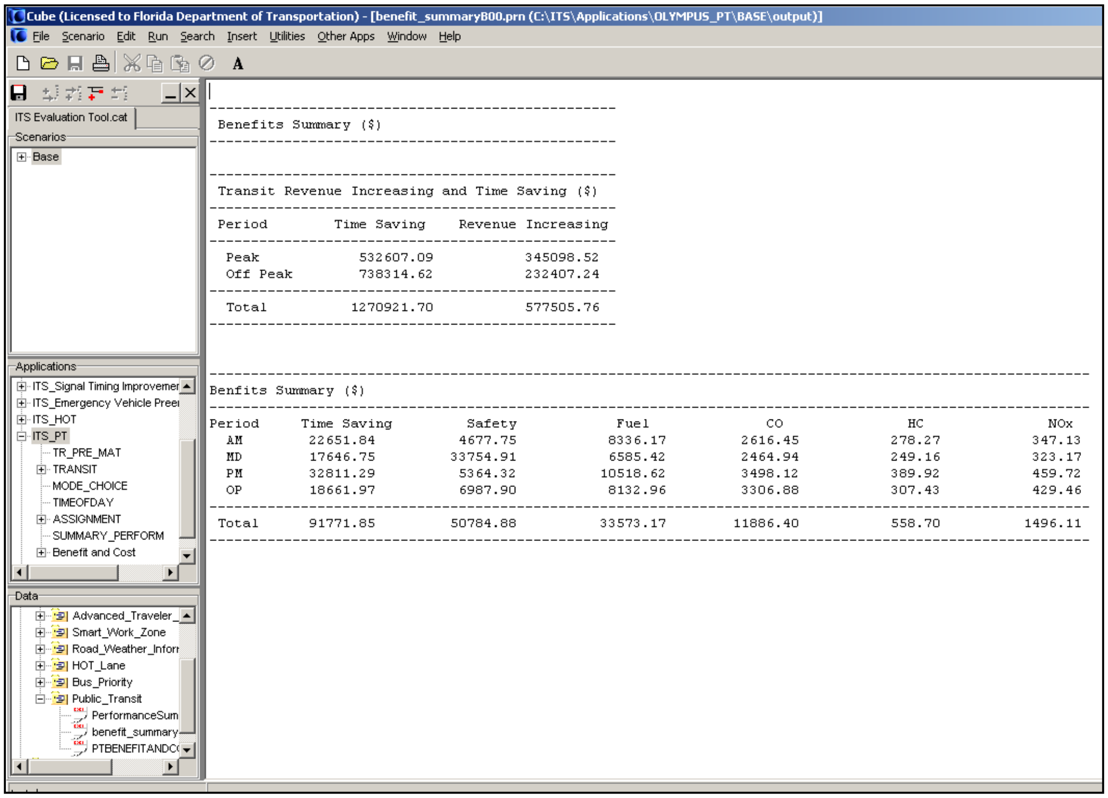


Figure 15-10 Benefit Summary Output File for APTS

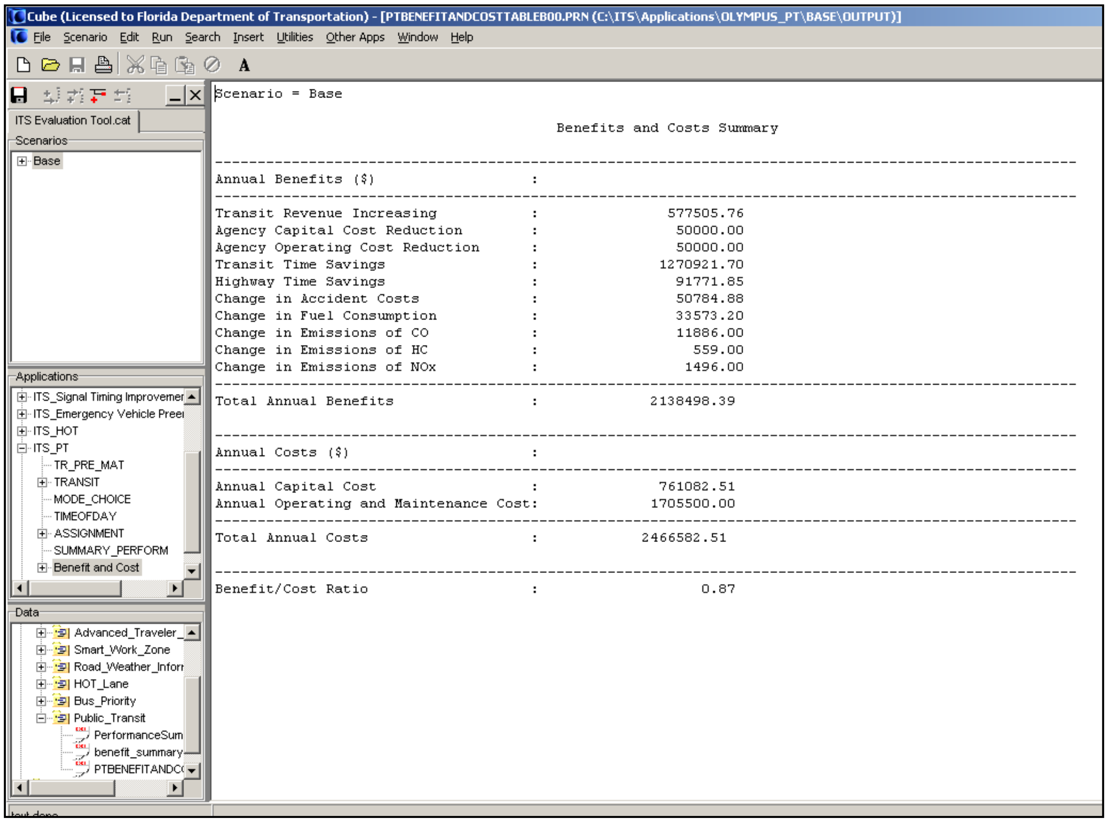


Figure 15-11 Benefit and Cost Summary Output File for APTS