A SENSITIVITY ANALYSIS OF THE MOBILITY-RELATED BENEFITS OF THE

ALABAMA SERVICE AND ASSISTANCE PATROL

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A SENSITIVITY ANALYSIS OF THE MOBILITY-RELATED BENEFITS OF THE ALABAMA SERVICE AND ASSISTANCE PATROL

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THESIS ABSTRACT

A SENSITIVITY ANALYSIS OF THE MOBILITY-RELATED BENEFITS OF THE ALABAMA SERVICE AND ASSISTANCE PATROL

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The Alabama Service and Assistance Patrol (ASAP) was developed by the Alabama Department of Transportation in an attempt to reduce non-recurring congestion in the Birmingham region of Alabama. This Freeway Service Patrol (FSP) uses roaming vehicles designed to quickly identify and clear traffic incidents upon the freeway network. These patrol vehicles help clear accidents, push stalled vehicles, and directly help customers in need to quickly restore capacity to the network. In performing these actions, ASAP creates mobility-related benefits as a result of reducing incident duration and delay. Calculation of mobility-related benefits is performed with assumptions of a variety of inputs within a traffic simulation process. These input assumptions are dropped through examination of a range of values as opposed to only considering one specific value. This thesis presents a sensitivity analysis of variations of these assumed inputs with respect to the mobility-related benefits generated by the ASAP program. The traffic simulation program CORSIM is applied to vary incident severity, location, time, and duration. Thirty unique scenarios are examined to estimate delay reduction based upon the assistance of an ASAP patrol vehicle. Further analysis is performed to include the effects of average vehicle occupancy and value of travel time upon generated benefits. Finally, the total estimated mobility-related benefits are compared to the corresponding costs. A benefit/cost range of 2.6:1 to 36.5:1 was calculated with a most likely value estimated at 14.4:1. These benefit/cost values indicate that the ASAP program is a cost-effective tool in implementing incident management within the Birmingham freeway network.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background

As current highway infrastructure ages and traffic volumes continually increase, traffic congestion is becoming a serious problem for major metropolitan areas within the United States. According to a report produced by the Texas Transportation Institute on U.S. urban mobility, in the decade between 1993 and 2003; peak periods have increased in length by seven percent, delay has grown from an annual average of 40 hours of travel up to 47 hours per person, and the percent of freeway mileage affected by congestion has grown from 51 to 60 percent. Essentially, congestion now affects more time of the day, more of the system, and creates extra time penalties (Schrank and Lomax, 2005). This congestion takes the form of both recurrent and non-recurrent delay. Recurrent congestion consists of the typical delay seen through high traffic volumes during the morning and afternoon peak hours. Conversely, non-recurrent congestion is often the result of more severe phenomena such as traffic incidents, special events, or construction.

To combat this increasing congestion, many state agencies have begun deployment of Freeway Service Patrols (FSP). FSP deployments provide incident management within the transportation infrastructure to help manage traffic flow, reduce congestion, enhance productivity, and save time and money. According to Fenno and

Ogden (1998), freeway service patrols are the single-most effective element of an incident management program in restoring network mobility. Many metropolitan areas have turned to using an FSP to help counter the effects of severe non-recurring congestion on the highway network. The first FSP service was developed in 1960 as the Chicago Emergency Traffic Patrol. Since then, over 50 FSP deployments have emerged across the United States (Fenno and Ogden, 1998). The primary goals of a freeway service patrol are to decrease detection time of incidents, decrease the duration of incidents, and reduce the risk of secondary accidents to motorists.

Freeway Service Patrols consist of a fleet of vehicles that roam the freeway network and help to combat non-recurring congestion through responsive incident clearance. These vehicles often target the high volume and high incident locations of the network served. FSP deployments have been shown to provide large benefits through enhanced mobility, emissions reductions, secondary crash reductions, and direct customer services. As stated, these deployments create these benefits through decreasing incident detection time and decreasing incident duration lengths. The onset of cellular devices and other forms of rapid communication have also enhanced the ability of FSP deployments within these roles.

Service patrol units improve mobility of the network through quick and efficient incident clearance. Patrol units are equipped with the necessary equipment to clear minor incidents from the highway. These units are not equipped to deal with large tractor-trailer incidents; however, the service patrol can provide a secondary role at the scene through efficient traffic control. The service patrol units are also often prepared with equipment designed for direct customer services. These items include gasoline, car jacks, booster cables, and first aid kits among others (Fenno and Ogden, 1998).

Many studies have been performed on various FSP agencies to determine the monetary benefit provided by these deployments compared to the inherent costs of the program. FSP deployments have initial costs due to purchasing new vehicles and equipment in addition to many annual costs incurred through operations, maintenance, and wage rates for employees. A benefit/cost evaluation is a useful tool as a benefit/cost ratio is an easily understood benchmark that details the cost-effectiveness of a program.

Translating the mobility, emissions, and customer savings to monetary amounts presents a complex analysis due to natural variability within traffic patterns and the existence of socioeconomic variables within the analysis. With regards to mobility, benefits are calculated with respect to the value of delay savings for motorists. This value is directly influenced by changeable inputs such as the location of the incident, time of the incident, incident duration reduction, the value of travel time, and average vehicle occupancy. To illustrate this variability, a range of benefit/cost ratios ranging from 2:1 to 36:1 for a variety of performed studies across the US has been reported (Fenno and Ogden, 1998). Due to this reason, a range of benefit/cost ratios that encompasses the range of reasonable values for these assumptions presents a more appropriate measure of effectiveness for the FSP as opposed to one single number. A benefit/cost range is most easily derived through the construction of a sensitivity analysis.

This study is being performed to evaluate the services of the Alabama Service and Assistance Patrol (ASAP) located in Birmingham, Alabama. This particular program was formed in June of 1997 as part of the Alabama Department of Transportation and has grown to cover over 100 miles of Alabama highways. The program was initially organized and funded through the Congestion Mitigation and Air Quality category of the Intermodal Surface Transportation Efficiency Act of 1991. ASAP service runs Monday through Friday from 6 a.m. to 10 p.m. The program is busy having conducted 17,090 assists during the 2005 year alone. This amount corresponds to approximately 66 assists per weekday.

1.2 Objectives

The objective of this report was to evaluate the effectiveness of the ASAP service patrol through construction of a sensitivity analysis. A model of the Birmingham freeway network, developed within the traffic simulation program CORSIM, was constructed for each of the ASAP programs operating hours. Using these models, the impact of ASAP assistance were simulated for a variety of scenarios. A sensitivity analysis was conducted to examine the effect of incident duration reduction, value of travel time, and average vehicle occupancy upon generated benefits. Conclusions were made, based upon the results, to serve as guidance for the future management of the ASAP program and recommendations for further research were provided.

1.3 Scope

The focus of this project was to examine the mobility benefits gained through the freeway service patrol ASAP. Vehicle incidents were simulated in a traffic simulation program for both “with” and “without” assistance cases to determine the impact of ASAP on non-recurrent congestion. Other potential benefits including environmental effects, crash reduction, and direct customer services are beyond the scope of this thesis. It is of importance to note that the many of the details of this project were considered in a manner as to be consistent with both past and ongoing projects surrounding the ASAP service.

This analysis had a base year 2005. The program was evaluated through a variety of simulated vehicular incidents and put through a sensitivity analysis measuring the cost-effectiveness of the ASAP program with regards to incident location, incident time, incident duration reduction, average vehicle occupancy, and value of travel time. This sensitivity analysis was performed to determine an accurate benefit range. This range reveals the potential mobility savings, to a high degree of confidence, for the ASAP program for a given year and provides an objective measure that details the value of the program.

1.4 Outline of This Thesis

Chapter 2 of this thesis is a literature review of previous studies that have been published with regards to this topic. These studies detail the methods and measures of effectiveness used to perform similar evaluations of freeway service patrols across the US. This information was consulted for guidance in selecting an appropriate method for conducting the vehicular simulations. In addition, reasonable guidelines were established for the variable inputs to be considered within the sensitivity analysis. Chapter 3 presents a methodology detailing the work involved in conducting this evaluation. Details are presented with regards to data collection, data management, model construction, and model calibration. In addition, selection criteria used to govern spatial and temporal distribution of the various vehicular incidents are provided. Finally, information detailing the construction of the sensitivity analysis and development of the mobility benefit calculations is given. Chapter 4 presents the results of this report. A range of mobility benefits is provided in addition to the corresponding range of benefit/cost ratios. Chapter 5 presents conclusions based upon the results. The final chapter explains the importance of the results and provides recommendations towards the future of the ASAP program. In addition, detail is provided that discusses how this information can be used for further research endeavors.

CHAPTER TWO

LITERATURE REVIEW

As a result of growing non-recurring congestion, a large number of metropolitan areas have created incident management programs designed to combat accumulating delay. A major facet of incident management programs is the deployment of freeway service patrols (FSP). These programs are designed to reduce incident durations, reduce delay, and increase mobility. In an effort to examine the impact of service patrols on the roadway network, many deployments have contracted out research programs designed to analyze the effectiveness of the FSP. Most specifically, these research efforts attempt to quantify benefits sustained from these service patrols and weigh them against the inherent costs. The growing number of FSP programs across the country has created a fairly extensive literature database that can be used to model and refine the methodology process for this particular study.

A comprehensive state of the practice report produced by Fenno and Ogden (1998) states, in citation, that, "Freeway service patrols have been cited as the single-most effective element of an incident management program for reducing incident detection time and incident duration." Nationwide, the primary goal of these programs is to quickly detect and respond to an incident and efficiently restore the freeway to its potential capacity. This goal is accomplished through a variety of means including contacting wrecker crews, direct customer benefits (e.g. providing gas), or providing advanced notification to surrounding traffic. This reduction in incident duration will amount to monetary benefits based upon mobility, emission reductions, secondary crash reductions, and direct customer services. Conversely, all of these services create annual program costs that can offset these benefits, spurring the need for a benefit-cost analysis.

2.1 Benefit/Cost Ratios

One of the first benefit-cost analyses conducted on freeway service patrols was performed in the Houston, TX region. This particular analysis found a benefit-cost ratio of 2:1 for the Houston FSP in 1973 (Fambro, 1976). This initial study set a high standard by examining benefits found through reduced delay, direct customer services, and safety enhancements. Delay reductions were calculated through customer questionnaires and estimated average stopped times and monetary savings were calculated through assumptions of values of travel time. This study was updated by the Texas Transportation Institute in 1993 with an evaluation of the South West Freeway Motorist Assistance Program. A much greater benefit-cost figure of 19:1 was discovered for the Houston FSP in this later effort by using updated computer simulations (Hawkins, 1993). This study utilized the computer simulation program FREQ10PC to simulate incidents on the freeway network and examine the impact of the FSP on delay. Similarly, a value of travel time was assumed to calculate monetary savings. An examination of the Los Angeles County Metro FSP was determined to have a benefit-cost ratio of greater than 5:1 for its services along an 8-mile of I-10 (Skabardonis et al., 1998). For this study, incident delay reductions were estimated through collection of field data with loops and probe vehicles. The benefit/cost ratios were established through consideration of delay reductions and fuel savings. A study conducted by Khattak and Rouphail (2003) on the Incident Management Assistance Patrols in North Carolina calculated benefit-cost figures of 3.5:1 in Asheville, NC and 4.3:1 in Raleigh, NC. The study conducted incident simulations with the traffic software FREEVAL. Similarly to the Houston study, these incident simulations were examined to determine the impact of FSP assistance on delay. An evaluation of the Freeway Incident Response Safety Team (FIRST) program in Minneapolis, MN found a higher benefit-cost ratio of 15.8:1 (MnDOT, 2004). This study also used a traffic simulation program, PARAMICS, to examine the impact of the FSP. Fuel savings and delay were considered in calculating monetary savings. A study performed in 2006 discovered a benefit-cost ratio of 4.4:1 for the Georgia Navigator program in Atlanta (GDOT, 2006). This study developed volume/time relationships to determine the impact of incidents on the freeway network. These relationships were applied to estimate the delay savings due to the FSP assistance. Finally, an analysis of Northern Virginia's safety service patrol revealed a benefit-cost ratio of 6.2:1 (Dougald et al., 2006). This study also used a microscopic simulation program to simulate incidents and evaluate the impact of the FSP.

Examination of these previously conducted studies revealed a common theme of examining delay savings for calculating mobility benefits. The most prevalent method for calculating delay savings was to apply specific incident durations for both with and without FSP assistance. Also, evaluation of these situations was often performed with a traffic simulation program. In addition, it is common practice to apply an assumed value of travel time to translate delay savings into monetary benefits. These common methodologies provide confidence in the similar proposed methodology for this study.

Using similar methods allows for comparisons to be made to this previously conducted research.

The study conducted by Fenno and Ogden includes a summary table containing the benefit-cost analysis figures for 15 freeway service patrol programs across the country. This particular table reveals benefit-cost ratios ranging from 2:1 to 36.2:1. Quite similarly, this literature review obtained similar benefit-cost ratios ranging from 2:1 up to 41.5:1. Table 2-1 depicts these calculated figures found through this review in addition to the location and date of the studies.

Table 2-1: Reviewed Benefit/Cost Ratios

Location	Year Conducted	B/C Ratio
Asheville, NC	2005	3.5:1
Atlanta, GA	2006	4.4:1
Florida	2005	2→ 41.5:1
Gary, IN	1999	4.71→13.28:1
Houston, TX	1973	2:1
Houston, TX	1993	19:1
Hudson Valley, NY	2006	4.47→ 9.85:1
Los Angeles, CA	1998	>5:1
Minneapolis, MN	2004	15.8:1
Northern Virginia	2006	6.2:1
Raleigh, NC	2005	4.3:1

This table reveals that, uniformly, all of these programs reviewed created greater monetary benefits than their respective costs indicating that the FSP element of incident management is cost-effective. However, the benefit-cost ratios calculated also reveal a very large amount of variability. This variability is expected as each FSP analysis incorporated different inputs within the benefit calculations. Service area, fleet size, program hours, travel time values, incident times, and service location will all affect the analysis results. In the same way, many studies incorporate the potential benefits from all areas previously mentioned (mobility, emissions, customer direct, etc.) while others only look at one or some of these areas.

As shown in Table 2-1, three studies determined a range of benefit-cost numbers depending upon a variability of inputs. An evaluation of the Hoosier Helper program out of Gary, IN calculated a range in ratios from 4.71:1 to 13.28:1 (Latoski et al., 1999). Likewise, a study of the Road Ranger Program in Florida calculated benefit-cost figures ranging from 2:1 to 41.5:1 (Hagen, 2005). Finally, a study performed on the Hudson Valley Highway Emergency Local Patrol (H.E.L.P.) program calculated benefit-cost numbers ranging from 4.47:1 to 9.85:1 (Haghani et al., 2006).

These last three studies reveal the potential variability of benefit/cost ratios that can be found for a particular FSP. The Hoosier Helper study understood the importance of examining the program throughout the entirety of its service period as the 4.71:1 ratio was calculated for daytime operation only and the 13.28:1 ratio was calculated for the entire 24-hour service (Latoski, et al., 1999). The study on the Highway Emergency Local Patrol of the Hudson Valley region examined the impact of varying incident durations on calculating benefit/cost ratios of the service patrol. This analysis was performed upon the idea that incident duration reductions will naturally vary on a case by case basis (Haghani et al., 2006). Finally, the study concerning the Road Ranger program in Florida recognized the importance of analyzing the patrol over a variety of locations throughout its entire network. This study reinforced the notion that service patrols will have significantly different impacts upon the highway network as dependant upon the location of assistance due to varying roadway geometries and traffic volumes(Hagen, 2005). These research efforts clearly reveal that the calculated benefits of a highway service patrol can vary dramatically when considering different locations, times, and incident durations within the analysis.

Regardless of the reasons the variability exists, an interesting scenario is presented by performing a sensitivity analysis upon many of the inputs presented in an attempt to create more refined and reliable benefit-cost figures. Accordingly, this analysis will serve to determine the relative effect each input has upon the final calculated figure. In using the ASAP program in Birmingham, AL as a network model, it is possible to perform this analysis with regards to value of travel time, average vehicle occupancy, difference between average incident duration with and without assistance, staging incidents at different times, and staging incidents at different locations. In addition, through the use of CORSIM freeway simulation software, incident location and incident times can also be varied for the same network. This literature review will help to characterize and limit the variability for these inputs that are to be analyzed.

2.2 Values of Travel Time

Within mobility studies, a great deal of debate and research has been performed in an effort to quantify the value of travel time for both passenger cars and trucks. With regard to benefit/cost projects of this nature; this input serves as a direct multiplier into benefit calculations of the service patrol. Based upon this characteristic, the assumed value of travel time can easily be responsible for a wide variability of results. A realistic range of values for quantifying travel time must be established to conduct an appropriate sensitivity analysis and to achieve reasonable results from the analysis.

Within the literature, the most popular resources for obtaining a travel time value appear to be either the Texas Transportation Institute (TTI) or the American Automobile Association (AAA). To calculate a travel time value, TTI looked at both delay costs and fuel costs associated with both trucks and passenger cars. Studies conducted in Florida (Hagen, 2005) and Virginia (Dougald et al., 2006) used these figures as the basis for their particular analyses. TTI provides estimates of the value of travel time for both passenger cars and commercial trucks. This information is released as part of its annual urban mobility study. It should be noted that, within the TTI study, the value for travel time was derived from the individual's perspective and not from the wage rate. The commercial cost value only includes the truck operating time and not the value of the commodities within. These nationwide average values were obtained based upon information collected from over 50 metropolitan areas across the country. In 2003, the urban mobility study released values of $13.75/hr for passenger cars and $72.65/hr for commercial trucks. The TTI numbers used in the Virginia study were slightly outdated at $13.45/hr and $71.05/hr.

In 1987, AAA produced a figure of $6/hr for passenger car. Unfortunately, a description of how this number was generated could not be found within the literature. Both the Hoosier Helper program in Indiana (Latoski et al., 2001) and the H.E.L.P. program in New York (Haghani et al., 2006) utilized this figure and adjusted it to the respective current year based off of a consumer price index (CPI). This adjustment yielded a value of $8.03/hr in 1995 for the Hoosier Helper study. In conjunction with these passenger car values, the same studies both utilized truck travel time values of $25.42/hr for single-unit truck and $28.33/hr for combination truck. These figures were obtained from the Highway Economics Requirement System. Generated in 1990, these values were derived as a function of truck driver wage rate, from the Bureau of Labor Statistics, and an estimated average value for cargo. Similarly, these two studies transformed the 1990 values into corresponding present numbers through the use of a consumer price index. The Hoosier Helper study calculated values of $8.03/hr and $30.38/hr through the consumer price adjustments. The Hudson Valley study combined both the passenger car and truck values into a total combination value of $15/hr. The CPI adjustment uses a historical base year value and an annual growth rate to determine the equivalent value in a future year. Equation 2-1 details the CPI adjustment method.

$$F = P * (1 + i)^n \tag{2-1}$$

Variable Definitions:

i = Interest Rate

F = AADT for year in question

P = Historical base year AADT

n = # of years between two given AADT values

The evaluation of the FIRST program in Minnesota used a travel time value of $10.04/hr for passenger cars and $18.61 for trucks. These figures were generated as a function of local wages (MnDOT, 2004). Similarly, an FSP study in North Carolina used a travel time value of $10/hr but did not provide reference information on the figure (Khattak et al., 2005). A study of the Georgia Navigator program in Atlanta utilized values of $19.14/hr for passenger car and $32.15/hr for truck. These numbers were directly obtained from the Bureau of Labor Statistics (GDOT, 2006). Finally, a study conducted in the Puget Sound region of Washington state utilized $12.40 per person-hour (Nee, et al., 2001). Consideration of all of these previously utilized numbers provided guidance in selecting an appropriate range of travel time values to conduct an effective sensitivity analysis for this input. Table 2-2 summarizes these values found in this literature review.

Table 2-2: Reviewed Values of Travel Time

Study	Citation	Year	Passenger Car ($/hr)	Truck ($/hr)
Florida	Hagen, 2005	2005	13.75	72.65
Northern Virginia	Dougald, 2006	2006	13.45	71.05
Gary, IN	Latoski et al., 2001	1999	8.03	30.38
Hudson Valley, NY	Haghani et al., 2006	2006	15	15
Atlanta, GA	GDOT, 2006	2006	19.14	32.15
Minneapolis, MN	MnDOT, 2004	2004	10.04	18.61
North Carolina	Khattak et al., 2005	2005	10.00	-
Puget Sound	Nee, et al., 2001	2001	12.40	-

2.3 Average Vehicle Occupancy

The average vehicle occupancy figures utilized during benefit/cost analyses can significantly alter results within mobility and delay studies. Assumed vehicle occupancy essentially acts as a multiplier in estimations of benefits. Similar to travel time values, an appropriate range of average vehicle occupancy figures must be established to avoid underestimating or overestimating the impact of service patrol involvement.

In consulting the literature, a limited number of studies were found that contained specific information regarding average vehicle occupancy used during their specific analyses. A study of the FSP in the Puget Sound Region assumed an average number of 1.2 passengers per vehicle (Nee et al., 2001). The evaluation of the FIRST program in Minneapolis, MN also used an average number of 1.2 passengers per vehicle (MnDOT, 2004). Justification for using these numbers was unable to found within these studies. The study of the Georgia Navigator Program in the Atlanta region utilized an average occupancy of 1.16 passengers per vehicle (GDOT, 2006). Finally, two brief occupancy counts, performed in the Birmingham, Alabama region in 2006 were provided by ALDOT. These studies provided “real-world” figures that serve as a strong resource in selecting appropriate occupancy numbers to be considered within this analysis. An occupancy count in Fultondale, Alabama found an average of 1.07 passengers per vehicle. This count was performed along I-65 Southbound from 7AM to 8AM. Similarly, a count in Pelham, Alabama found an average of 1.09 passengers per vehicle. This count was performed along I-65 Northbound between 7AM and 8AM (He, 2007). This range of values, especially those found in the Birmingham region, should provide an appropriate spectrum to conduct an effective sensitivity analysis with regards to this input. Table 2-3 summarizes the average vehicle occupancy values found within the literature review.

Table 2-3: Reviewed Values of Average Vehicle Occupancy

Study	Citation	Year	Average Vehicle Occupancy
Puget Sound	Nee et al., 2001	2001	1.2
Minneapolis, MN	MnDOT, 2004	2004	1.2
Atlanta, GA	GDOT, 2006	2006	1.16
Fultondale, AL	He, 2007	2006	1.07
Pelham, AL	He, 2007	2006	1.09

2.4 Average Incident Durations: With & Without Assistance

It is well known that the large benefits found through freeway service patrol and incident management programs are generated by restoring capacity as quickly as possible with the onset of non-recurring congestion. Based upon this fact, a large amount of information available in the literature is devoted towards quantifying average incident duration. Most specifically, researchers are interested in examining the impact of service patrols on the differences between incident durations with and without FSP assistance. An entire incident duration is comprised of three critical components. These include detection and verification, response, and clearance. The majority of the studies considered found substantial reductions in total incident durations with the implementation of an FSP with respect to quicker detection and response times. As many freeway service patrol units are often not equipped for clearing severe incidents; clearance time reductions were not as significant as the other two periods. Comparisons were often made through recorded differences between unassisted incident durations and assisted incident durations in FSP time logs. Service patrols commonly record incident assists with regards to time of arrival, time of clearance, and time of departure within these logs. Naturally, these logs are a valuable asset in analyzing the impact of service patrols on duration lengths. The ASAP program similarly uses these time logs for its record purposes.

An evaluation of the FSP in Los Angeles County found that non-assisted incidents had longer durations as compared to those where a patrol unit was present. On average, the incident duration reductions within this network ranged from 7-20 minutes when the FSP was present. The FSP was found to reduce response times by up to 15 minutes whereas any remaining reduction was attributed to quicker detection times. The study presents specific examples along I-880 in which incident durations were reduced from 37.6 minutes to 21.1 minutes (Skabardonis et al., 1998). The evaluation also cites studies of the Boston motorist assistance program and the Chicago emergency traffic patrols. These two programs were found to reduce incident durations by 15 minutes and 20 minutes, respectively (Skarbardonis et al., 1998).

Other studies found similar incident duration reductions. An analysis of the Georgia Navigator program in Atlanta discovered a 23 minute reduction in average incident duration with the assistance of a patrol unit (GDOT, 2006). Similarly, the analysis of the FIRST program in Minnesota found reductions of up to 8 minutes (MnDOT, 2004). Additionally, an evaluation of the South West Freeway Motorist Assistance Program in Houston found an average incident reduction of 16.5 minutes. Freeway incident durations fell from an average of 46.5 minutes without assistance to 30 minutes with assistance (Hawkins, 1993). An analysis of the freeway courtesy patrols in Houston in 1973 revealed that incident duration fell from an average of 49 minutes down to 27 minutes with the help of the patrol (Fambro, 1973).

Focusing solely on response times, a study of the Puget Sound freeway service patrol found response time reductions between 44 and 77 percent. This percentage reduction corresponds to actual response times falling from between 5-10 minutes down to less than 5 minutes (Nee et al., 2001). Similarly, the Hoosier Helper program in Indiana found 10 minute duration reductions in-lane incidents and 15 minute duration reductions for other less severe incidents with the presence of the service patrol (Latoski et al., 1999). Finally, a performance analysis of Virginia's service patrols calculated a 17 percent average reduction in incident durations with assistance from the FSP. This reduction corresponds to an 11 minute reduction for shoulder incidents and a 9.5 minute reduction for in-lane incidents (Dougald et al., 2006).

It is plain to see that a wealth of knowledge exists upon the impact of service patrols on minimizing incident durations. Again, this large amount of information was expected as the reduction of incident durations illustrates the potential of an FSP to develop mobility related benefits. These studies considered revealed varied and yet consistent reductions of incident durations from 5 minutes up to 25 minutes due to the assistance of freeway service patrols. This information provides ample reinforcement for establishing bounds concerning this aspect of the sensitivity analysis to be performed. Table 2-4 presents these values discussed.

Table 2-4: Reviewed Values of Incident Duration Reduction

Study	Citation	Year	Incident Duration Reduction (min)
Los Angeles, CA	Skarbardonis et al., 1998	1998	7-20
Boston, MA	Skarbardonis et al., 1998	1998	15
Chicago, IL	Skarbardonis et al., 1998	1998	20
Atlanta, GA	GDOT, 2006	2006	23
Houston, TX	Hawkins, 1993	1993	16.5
Houston, TX	Fambro, 1973	1973	22
Puget Sound	Nee et al., 2001	2001	5-10
Gary, IN	Latoski et al., 1999	1999	10-15
Northern Virginia	Dougald et al., 2006	2006	11

2.5 Staging Incidents at Different Locations

The vast majority of the projects considered within this literature review went through extensive research to determine the locations of highest incidents, highest volumes, etc. that were served by the freeway service patrol in question. Naturally, an incident occurring on high volume roadways can create an extremely large amount of non-recurring congestion. This congestion leads to massive costs incurred by the users of the roadway. Conversely, the assistance from an FSP can greatly reduce this congestion and create extremely large benefits in these situations. Although this worst case scenario reveals the potential benefits of an FSP to its highest extent, it does not calculate a true and encompassing average benefit for the entire service area.

However, a few notable examples do stray from the norm in attempting to consider the entirety of the network in question when quantifying the impact of the FSP. The examination of the Road Ranger program does try to account for the entire service area by varying the location of considered incidents over all 5 districts across the entire state (Hagen et al., 2005). Similarly, a study of the FIRST program in Minnesota stated that incidents were varied over a series of locations to encompass the entire service area. Unfortunately, no specifics were found as to the details of the locations considered for this project (MnDOT, 2004). Neither of these two studies limited the scope of their respective projects to portions of the roadway network. It is imperative to consider the entire service area to fully grasp the potential impacts of a service patrol organization.

2.6 Staging Incidents at Different Times

Under a similar notion, the worst case scenario for freeway incidents often occurs during peak period conditions within major metropolitan areas. These conditions are normally represented by at-capacity or near-capacity situations on the highway network. Naturally, these high traffic volumes can lead to high rates of incident occurrences. It is within these conditions that the maximum potential benefits from the service patrol can be realized. Based upon this reasoning, most FSP evaluations examine or simulate incidents during weekday peak periods.

For example, the evaluation of the Los Angeles program examined the effectiveness of the service patrol during weekday AM and PM peaks (Skarbardonis et al., 1998). Once again, reducing the scope of the analysis to the peak periods often inappropriately ignores the performance of the service patrol during the rest of the day. The weekday peaks periods do not fully encompass the services provided by most freeway patrols and may lead to unrealistic estimates of the possible benefits from these services. To understand the full impact of these services, the service patrol must be examined throughout the entirety of its service hours.

Again, a few examples do take a broader view in varying incident time. The evaluation of the Hoosier Helper program in Indiana considered model simulations for both weekday periods and weekend periods (Latoski et al., 1999). More extensively, the study of the North Carolina FSP created average annual daily traffic profiles for each day of the week within the service area. Based upon these numbers, 8 hourly categories were created for model simulation. These categories were reduced to 5 urban models and 3 rural models that each represented a different period of the day (Khattak et al., 2005).

This literature review has provided a wealth of information that was used to help direct the methodology of this thesis. The information summarized in this chapter presents guidelines for the variable inputs that were considered within the sensitivity analysis of this project.

CHAPTER THREE

METHODOLOGY

This project is focused upon estimating the benefits of the Alabama Service and Assistance Patrol by examining the effects of differing incident management characteristics against calculated dollar benefits. To measure the effectiveness of the ASAP program, total vehicle hours of delay were calculated through "mock" incident simulations. These scenarios were used to approximate delay both with an ASAP unit assistance and without ASAP assistance. The vehicle-hour difference found between the scenarios run with ASAP assistance as compared to the scenarios without ASAP assistance represent the mobility benefits gained from the use of this program. Due to the variability found within network-wide traffic, a sensitivity analysis was essential to capture an appropriate range of dollar benefits. This range is designed to illustrate the total scale of ASAP effectiveness.

This list provides a general outline of the methodology used for this study and highlights the main focal points of this procedure. This methodology will go into greater detail on each section throughout the chapter.

1) Model Construction within CORSIM
   a) Data Collection – ALDOT hourly volumes, Statewide AADT Map
   b) Fill in network with ALDOT hourly volumes – Interpolation
   c) Apply entry/exit volumes, ramp splits

2) Determine Incident Scenarios – 30 Scenarios

   a) Random number generation used to determine spatial and temporal variations

   b) Simulate the Scenarios within CORSIM

   c) 6 Variations of incident duration for each scenario, 5 with assistance, 1 without assistance

   d) Calculate difference of vehicle-hours of travel time as measure of effectiveness

3) Sensitivity Analysis

   a) Average Vehicle Occupancy

   b) Value of Travel Time

4) Benefit Calculations – Cross-Classification Procedure

5) Cost Calculations

6) Benefit/Cost Calculation

The review of literature regarding freeway service patrols provided insight towards creating a suitable methodology for this sensitivity analysis to be performed. An adequate staging ground was constructed to begin choosing input variations for the different characteristics of incident management in question. Incident duration, location, and time were varied within the sensitivity analysis through an examination of multiple scenarios that accommodated these characteristics. These different scenarios calculated differing total vehicle hours of delay due to changed traffic patterns, volumes, and network site-characteristics. The traffic simulation program CORSIM was used to imitate these changing scenarios. Similarly, variations of travel time values and vehicle occupancy figures were applied to the calculated hours of delay to approximate dollar amounts.

Within this methodology, specific sections are provided detailing the process performed for each of the five input characteristics that were varied in the sensitivity analysis. Variations in the value of travel time, average vehicle occupancy, incident locations, incident durations, and incident times were identified to create an effective analysis that encompasses the variability surrounding these benefit/cost analyses. These particular inputs were observed as the most dramatic variables that differed within the literature review. Most studies contained unique values of travel time and average vehicle occupancy. Similarly, incident simulations differed greatly between studies with regards to location, time, and duration. All five of these characteristics were thought to have a vital role in assessing positive impacts of incident management services and their varying effects to be modeled. These stated characteristic variations were deemed suitable to fully capture the potential range of mobility-related benefits that might be found through the Alabama Service and Assistance Patrol (ASAP).

Before a sensitivity analysis was performed, a method for estimating the total vehicle hours of delay was established. The microscopic traffic simulation model program CORSIM was chosen to help analyze the potential impact of the ASAP vehicles on incident management. CORSIM is a sub-program that falls under the umbrella of the Traffic Software Integrated System (TSIS). This program allows the creation of benefit/cost analyses through traffic network model construction, traffic simulation analysis, and execution of the traffic simulation models. TSIS-CORSIM is a valuable setup to identify the complete impact of incident management throughout the entire interstate network covered by the ASAP patrol units. This program is often used to examine microscopic traffic simulation models such as those being performed in this study.

The CORSIM program allows the creation of a variety of roadway networks through link and node construction. The software contains simple construction tools that can be used to build any network desired. User-defined traffic volumes can be loaded onto the constructed network through simulated entry and exit points. These networks can be tested for a given measure of effectiveness under a variety of traffic scenarios. Traffic behavior within the program is governed by accepted traffic theory and driver behavior models. The CORSIM program works in a stochastic manner by assigning random numbers to driver behaviors and vehicle characteristics. This information is governed through internal random seed generation. To arrive at an accurate representation of a particular measure of effectiveness, a scenario should be run several times using different random seed numbers.

3.1 Model Construction

A fully-constructed model detailing the entire ASAP interstate coverage was provided for this project within TSIS-CORSIM. The ASAP coverage area runs from exit 130 to exit 144 along I-20, exit 104 to exit 143 along I-59, exit 238 to exit 275 along I-65, and exit 10 to exit 32 along I-459. A total of 112 miles of interstate are serviced by this program. Figure 3-1 illustrates the complete ASAP coverage area.

However, the constructed model had to be adjusted with regards to traffic volumes for the purposes of conducting the sensitivity analysis. CORSIM networks are constructed as a series of links and nodes designed to emulate a particular roadway network. Vehicles enter the network through designated entry nodes and leave the network through designated exit nodes. CORSIM requires specific vehicle volumes entering the network for a particular simulation at each entry node in addition to specific vehicle volumes exiting the network at each exit node.

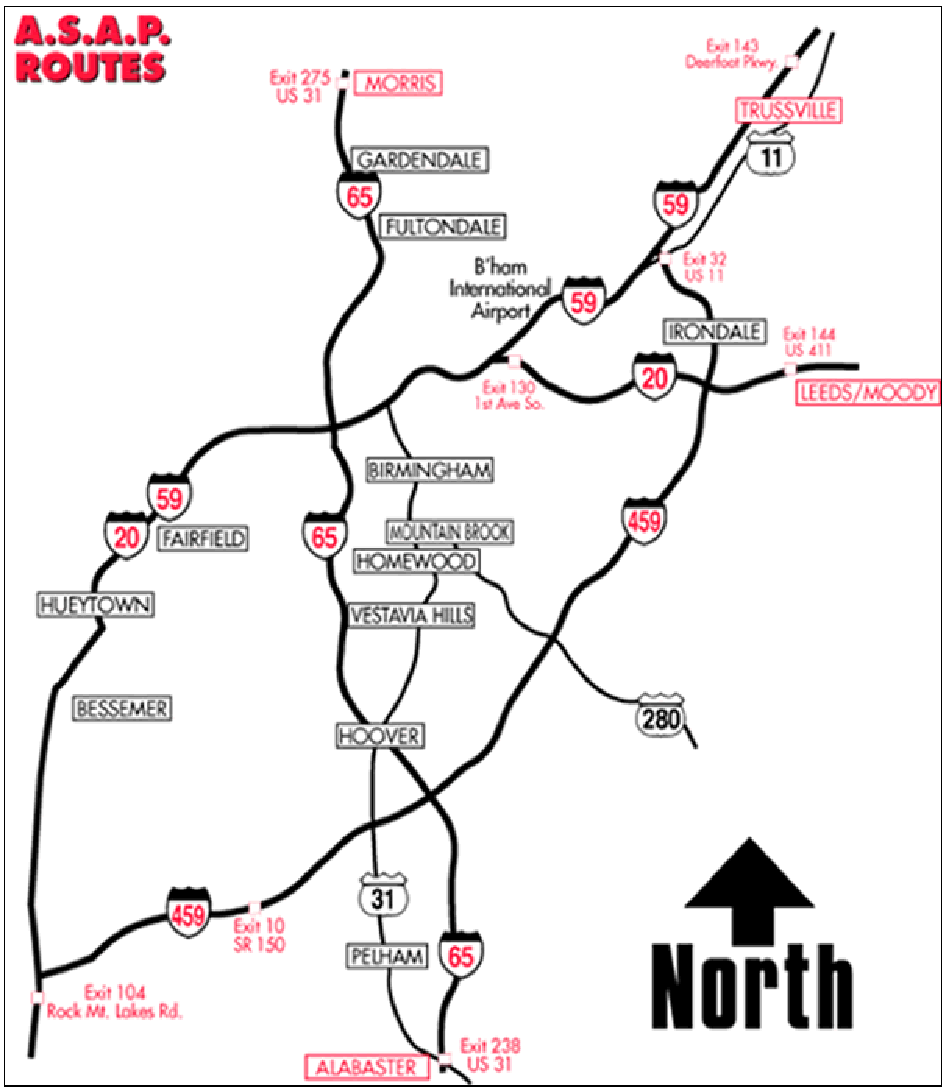

Figure 3-1: ASAP Coverage Area

The given model was constructed for simulation use during the 7-8AM peak hour. As the sensitivity analysis is designed to vary the staging time of incidents throughout the day, the provided model had to be similarly constructed for the remaining 15 hours that fall within the ASAP coverage time period. The ASAP operating time period runs from 6:00 a.m. to 10:00 p.m. This lengthy process created 16 unique models that can be used to perform incident simulations for any particular hour of the coverage period.

3.1.1 Data Collection/Management

The Alabama Department of Transportation (ALDOT) provided hourly 24-hr traffic counts for the majority of the Birmingham interstate network. Through the use of these hourly counts and an equilibrium principle, traffic volumes can be calculated for use in the CORSIM network simulations. For this project, Thursday counts were used. This middle-of-the-week data minimizes the potential for uncharacteristic traffic behavior that might be found around the weekends. In addition, Thursday was chosen over Tuesday and Wednesday counts as it was the day of the week with the most complete provided coverage. The ALDOT provided data covers about 75% of the entire Birmingham network and ranges from hourly counts taken from 2002 to 2005. For consistency, all hourly counts were converted to equivalent 2005 values based upon annual growth rates of the corresponding Average Annual Daily Traffic (AADT) in the same area. AADT values were obtained through the online ALDOT statewide traffic volume map (ALDOT, 2007). This map contains historical AADT information for all counting stations across the state of Alabama and has complete coverage of the

Birmingham area. Annual growth rates were calculated based upon the standard equation as depicted in equation 3-1.

$$i = \left(\frac{F}{P}\right)^{\frac{1}{n}} - 1 \qquad (3\text{-}1)$$

Variable Definitions:

i = Interest Rate

F = AADT for year in question

P = Historical base year AADT

n = # of years between two given AADT values

3.1.2 Data Interpolation

Two methods of interpolation were utilized to calculate the hourly volumes of the remaining 25% of the network that was not available from the ALDOT counts. The first interpolation scenario involved two intersections along a given portion of roadway. The sections upstream and downstream of the intersections have known hourly volumes whereas the section between the intersections has an unknown volume. The second interpolation scenario involved prior knowledge of hourly counts for only one section of roadway. The remaining sections of roadway through to the end of the coverage area have unknown hourly volumes. These interpolation methods are based upon the ALDOT AADT numbers found through the statewide traffic volume map and were used to assume approximate volumes for the areas in question.

For the initial interpolation method, the three AADT values corresponding to the hourly counts of interest were utilized. First, the difference between the upstream and downstream AADT values was calculated. Similarly, the difference between the upstream AADT value and middle AADT value was calculated. Secondly, a ratio of the difference between these two numbers was calculated. Finally, this ratio was then applied to the corresponding difference found between the given hourly volumes of the upstream and downstream sections. This ratio volume was then added to the upstream volume for an interpolated hourly count based upon AADT. Figure 3-2, Equation 3-2, and Table 3-1 provide detail to further illustrate this process.

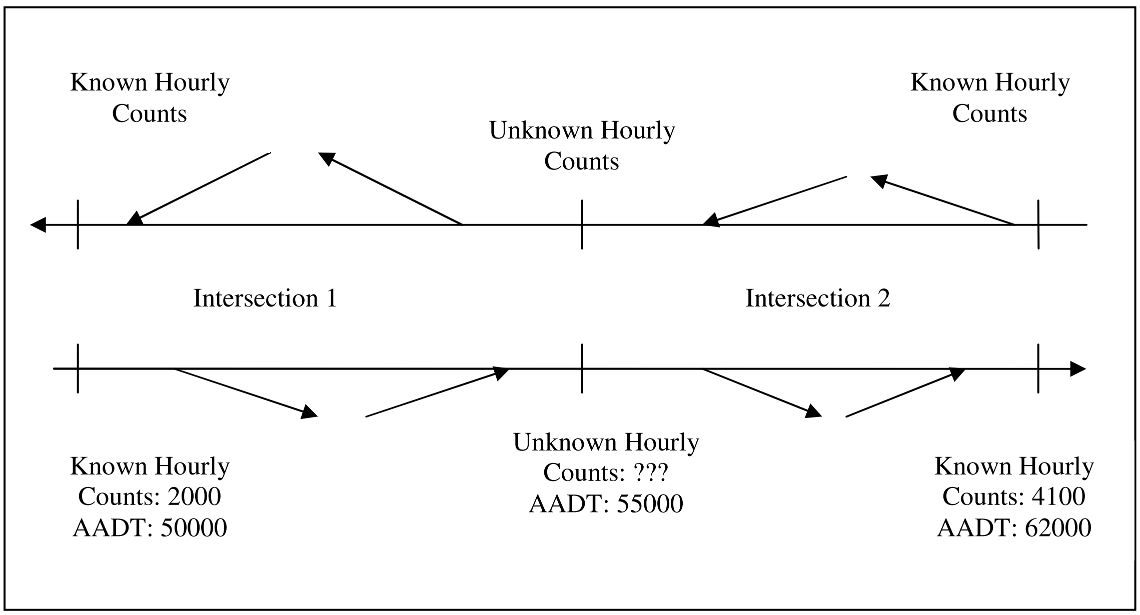

Figure 3-2: Interpolation Method One Illustration

$$IV = \left[GV + (R)(GHD)\right] \quad (3\text{-}2)$$

Variable Definitions:

IV= Interpolated Value

GV= Given Value

R= Ratio of Difference in AADT

GHD= Given Hourly Difference

Table 3-1: Interpolation Method One Example

2005 AADT	Given Hourly Data (veh/hr) (missing value*)	Difference in AADT between Stations	Proportion of the Difference in AADT Stations	Hourly Data used for analysis (Interpolated Value*)
50000	2000	5000		2000
55000	-*	7000	0.42	**2875***
62000	4100		0.58	4100
	Difference=2100	12000		

Example Calculation: $IV = \left[2000 + \left(\frac{55000 - 50000}{62000 - 50000} \right) (4100 - 2000) \right] = 2875$

The second method of interpolation involved knowing the hourly counts of one upstream section of roadway with one or multiple unknown values downstream. The downstream hourly counts were similarly interpolated based upon corresponding AADT numbers. First, the ratio of the AADT from the section with the known hourly counts as compared to the AADT of the next downstream was calculated. Secondly, the same ratio was applied to the known hourly counts to calculate interpolated hourly counts for the unknown section. This process can be repeated for any number of unknown sections to fill in the entire network with approximate hourly counts as based upon AADT numbers. This method was often required when hourly counts were not available at the end of the ASAP coverage area. Figure 3-3, Equation 3-3, and Table 3-2 provide detail to further illustrate this process.

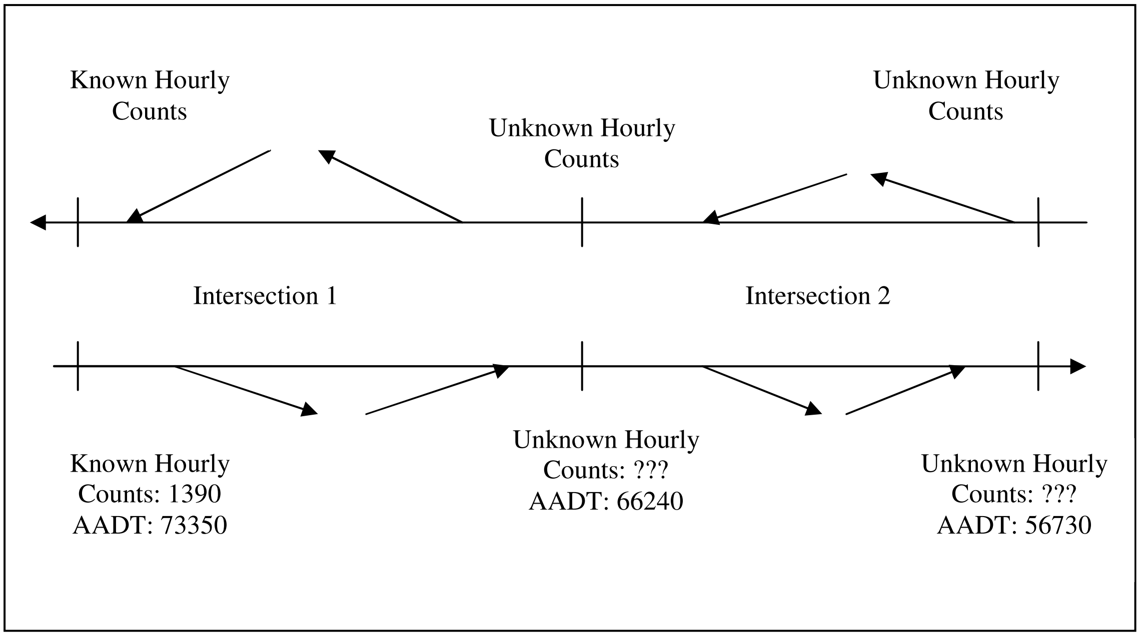

Figure 3-3: Interpolation Method Two Illustration

$$IV = (GV)(R) \tag{3-3}$$

Variable Definitions:

IV= Interpolated Value

GV= Given Value

R= Ratio of Difference in AADT

Table 3-2: Interpolation Method Two Example

AADT	Ratio of change in AADT	Hourly Data used for analysis (Interpolated Value*)
80750		1453
73350	0.9084	1390
66240	0.9031	1255*
56730	0.8564	1075*
41080	0.7241	778*

Example Calculation: $IV = (1390)\left(\frac{66240}{73350}\right) = 1255$

3.1.3 Ramp Split Calculations

With 100% of the hourly counts calculated for the entire network, entry and exit volumes within the CORSIM network were calculated based upon a principle of equilibrium. To run a simulation, CORSIM requires specific volumes for each entry and exit node that are found at the edges of the network and at every interchange. These entry and exit volumes were individually calibrated to correspond to the hourly volumes already determined for the highway sections being considered. For instance, if section A has a specific hourly count of 1800 vehicles and section B has an hourly count of 2000 vehicles, it is clear that a net change of +200 vehicles must occur at the interchange within these sections.

An assumed exit rate of 10% exiting and 90% continuing through was used unless a specific situation required a different rate. This assumption was made for consistency purposes as there are many different possible exit and entry rates that could work for any given interchange. In adjusting the network, many situations were encountered that required the use of different exit/entry rates. For example, if upstream segment A has 2200 vehicles in a given hour and downstream segment B has 1800 vehicles per hour, a 10% exit rate is not large enough to account for the sharp decline in volume. For this particular example, a larger exit rate would be needed to satisfy equilibrium.

Without real data available, this assumption had to be made using engineering judgment. For most situations, a 10% exiting and 90% continuing split appeared to be a realistic and plausible model of the traffic flow. Again, many situations were encountered in which differing splits were used as based upon capacity constraints.

If possible, the entry/exit rates were kept constant throughout all 16 hours of the day for consistency and simplicity. Again, each interchange has many different possibilities for entry/exit rates which are each as plausible as the next creating the need for this judgment to be made. An entry limit of 1800 vehicles/hour/lane was placed upon entry to satisfy capacity constraints as recommended by the Highway Capacity Manual (HCM, 2000). Situations were encountered in which entry capacity restraint was exceeded for a particular hour when a constant entry/exit was applied throughout the day. For these particular hours, the entry/exit rates were individually adjusted to lower the volumes below the capacity constraint in an attempt to avoid unnecessary congestion within the model.

Engineering judgment was also applied to these entry and exit volumes in an effort to keep the data realistic and appropriate. For instance, if an applied constant exit split fulfilled the entry volume capacity requirement over the entire 16 hours but did not appear plausible, judgment was used to alter the exit splits into something more feasible. For example, if, at a given interchange, the 6AM entry volume was 700 vehicles, the 7AM volume was 50 vehicles, and the 8AM volume was 900 vehicles; the 7AM exit split would be altered to create an entry volume more in-line with those surrounding. These adjustments are necessary due to counting errors often found in data of this type and magnitude. These errors are most often the result of an equipment malfunction.

The Birmingham network has 6 major interstate interchanges consisting of I-65 & I-59, I-65 & I-459, I-59 & I-20, I-20 & I-459, and two interchanges of I-59 & I-459. ALDOT provided traffic counts of entering and exiting traffic volumes for each of these six interchanges, however, ramp split information was not available. The CORSIM network provided included "dummy" entry and exit ramps that were used to equilibrate the incoming and outgoing traffic volumes as these numbers were not always equal. The differences in entry and exit volumes for each hour and each interchange were typically within 5% creating the need for using these "dummy" links. As opposed to using these false entry and exit points, this project relied on slightly altering the given traffic volumes to have equal incoming and outgoing amounts. A 5% total difference created extremely small alterations when applied to all 4 entry and exit points. This level of change was determined to be acceptable given the variable nature of traffic counts.

To arrive at an appropriate solution of traffic distribution within the interchange, the entry and exit volumes had to be set equal through volume distribution. The distribution was weighted based upon the counted traffic volumes. For instance, if one entry point supplied 20% of the volume into the interchange, then 20% of half of the difference would be added or subtracted to the original counted volumes. Once performed for each entry and exit point into the interchange, the total volumes were equalized. Table 3-3 and equation 3-4 illustrate this process.

Table 3-3: Typical 4-way Interchange Equalization Process

Entry Volumes	Exit Volumes	Total Volume Difference	Entry Volume Change	Entry Volume Change
1000	800		-(1000/3600)*100	-28
700	600	3600-3400 = **200**	-(700/3600)*100	-19
800	1200		-(800/3600)*100	-22
1100	800	200/2 = **100**	-(1100/3600)*100	-31
∑ = 3600	∑ = 3400			-100

New Entry Volumes	New Exit Volumes
972	824
681	618
778	1235
1069	824
3500	3500

$$NewVolume = OldVolume \pm \left(\frac{OldVolume}{TotalVolume} \right) * \left(\frac{Difference}{2} \right) \tag{3-4}$$

With equal volumes coming in and out of the interchanges, the individual ramp volumes were calculated using both engineering judgment and capacity restraints as discussed. The primary motivation of these methods was to arrive at numbers that were realistic and appropriate. Further guidance was provided from real ramp counts of the I-59/I-65 interchange by ALDOT. These counts were used to calculate actual ramp splits of this particular interchange dropping the split assumptions for this particular interchange. It should be noted that a comparison of the estimated interchange splits assumed through engineering judgment and capacity restraints and the actual ramp splits calculated through real data revealed a negligible difference. This comparison gives confidence to applying similar judgment to all the interchanges throughout the network.

With the complete entry/exit rates determined for the entire model through the methods described above, 16 unique models (6AM – 10PM) were created for each hour of the ASAP coverage time. Each model corresponded to the ALDOT provided hourly volumes and calculated hourly volumes discussed. These models were used for conducting incident management simulations to determine the potential benefits of the ASAP patrol units.

3.2 Determining Incident Scenarios through Temporal & Spatial Variation

As stated, many previous studies that have looked into a benefit/cost analysis of incident management programs made the decision of simulating the worst case scenario in an attempt to maximize potential benefits. This approach naturally illustrates the "greatest amount of good" a service patrol unit can produce. However, it is plain to see that real-life incidents do not always occur when the greatest potential benefit is possible. Incidents have been known to take place throughout the day and across the entire traffic network.

To capture the variability found among incidents, 30 unique scenarios were randomly chosen, each with a different location and time. Thirty unique scenarios were chosen as this amount corresponds to a "large" data set as shown through the Central Limit Theorem. This characteristic is important in attempting to encompass the entire range of possible ASAP benefits. There are 1758 links within the Birmingham CORSIM network discounting both entry and exit links. The links in which to simulate incidents were chosen randomly through random number generation between the values of 1 and 1758. The chosen number corresponds to the upstream node of the link used for simulation. This random number generation was performed using the "rand" function within Microsoft Excel.

In a similar manner, the randomness found within incident temporal occurrences in the Birmingham network was accounted for through random number generation within Microsoft Excel. The ASAP program operates Monday through Friday between the hours of 6AM and 10PM. Random incident times were chosen by generating a random number between 600 and 2200. If the random number falls between 600 and 700 for instance, the incident was to be simulated with the 6-7AM network model. For this method, the lower bound (600) was inclusive, and the upper bound (700) was exclusive.

A random number of 700 indicates a scenario simulation using the 7-8AM network, whereas a random number of 800 uses the 8-9AM network and so on.

Finally, incident severity, with regards to lane blockages, was taken into account through analysis of the 2004-2005 ASAP logbooks. These logbooks described every ASAP assist from July 1, 2004 to July 1, 2005. An investigation of 16,890 incidents that had recorded incident severity data revealed a total of 14,850 shoulder incidents (87.92%), 1,355 one-lane incidents (8.02%), 472 two-lane incidents (2.80%), and 213 (1.26%) incidents in which greater than three lanes were blocked. This distribution was applied to all 30 scenarios being performed in a random manner. Applying this distribution created 24 shoulder incident scenarios, 4 one-lane blocked scenarios and 2 two-lane blocked scenarios. Table 3-4 details all 30 scenarios that were chosen through this method described. Within this table, shoulder incidents are designated as having zero lanes blocked. Figure 3-4 illustrates the spatial distribution of the 30 scenarios. Each incident location is designated as a circle.

Table 3-4: 30 Unique Incident Scenarios

Scenario	Incident Link		Time of Day		Number of Lanes blocked
	Highest- 1758	Lowest- 1	Highest - 2200	Lowest - 600	
					Highest
	Random Node	Assigned Link	Random Number	Assigned Time	Lowest
1	1255	(1255, 1258)	867	8 am - 9 am	1
2	874	(874, 875)	1608	4 pm -5 pm	0
3	683	(683, 684)	1630	4 pm -5 pm	0
4	307	(310, 307)	2049	3 pm - 4 pm	0
5	507	(505, 507)	707	7am - 8 am	1
6	168	(168, 169)	1018	10 am -11am	0
7	421	(421, 422)	1757	5 pm- 6 pm	2
8	807	(807, 809)	1689	4 pm - 5 pm	0
9	155	(154, 155)	2178	9 pm -10 pm	0
10	743	(743, 744)	1239	12 pm -1 pm	0
11	1130	(1130, 1133)	1087	10 am - 11 am	0
12	1502	(1502, 1504)	1174	11 am - 12 pm	0
13	1513	(1511, 1513)	603	6 am - 7 am	1
14	611	(611, 612)	1897	6 pm - 7 pm	0
15	826	(826, 827)	1886	6 pm - 7 pm	0
16	923	(923, 924)	1978	7 pm - 8 pm	0
17	385	(385, 388)	2142	9 pm - 10 pm	0
18	699	(699, 701)	1418	2 pm - 3 pm	0
19	1360	(1360, 1363)	1880	6 pm - 7 pm	0
20	1278	(1278, 1279)	2002	8 pm - 9 pm	0
21	659	(659, 660)	864	8 am - 9 am	0
22	59	(59, 60)	1769	5 pm - 6 pm	0
23	1735	(1735, 1736)	1712	5 pm - 6 pm	2
24	1558	(1558, 1559)	1975	7 pm - 8 pm	1
25	458	(458, 459)	2051	8 pm - 9 pm	0
26	1096	(1096, 1097)	1458	2 pm - 3 pm	0
27	852	(852, 854)	1408	2 pm - 3 pm	0
28	536	(536, 537)	1158	11 am - 12 pm	0
29	1567	(1567, 1568)	764	7 am - 8 am	0
30	1387	(1386, 1387)	768	7 am - 8 am	0

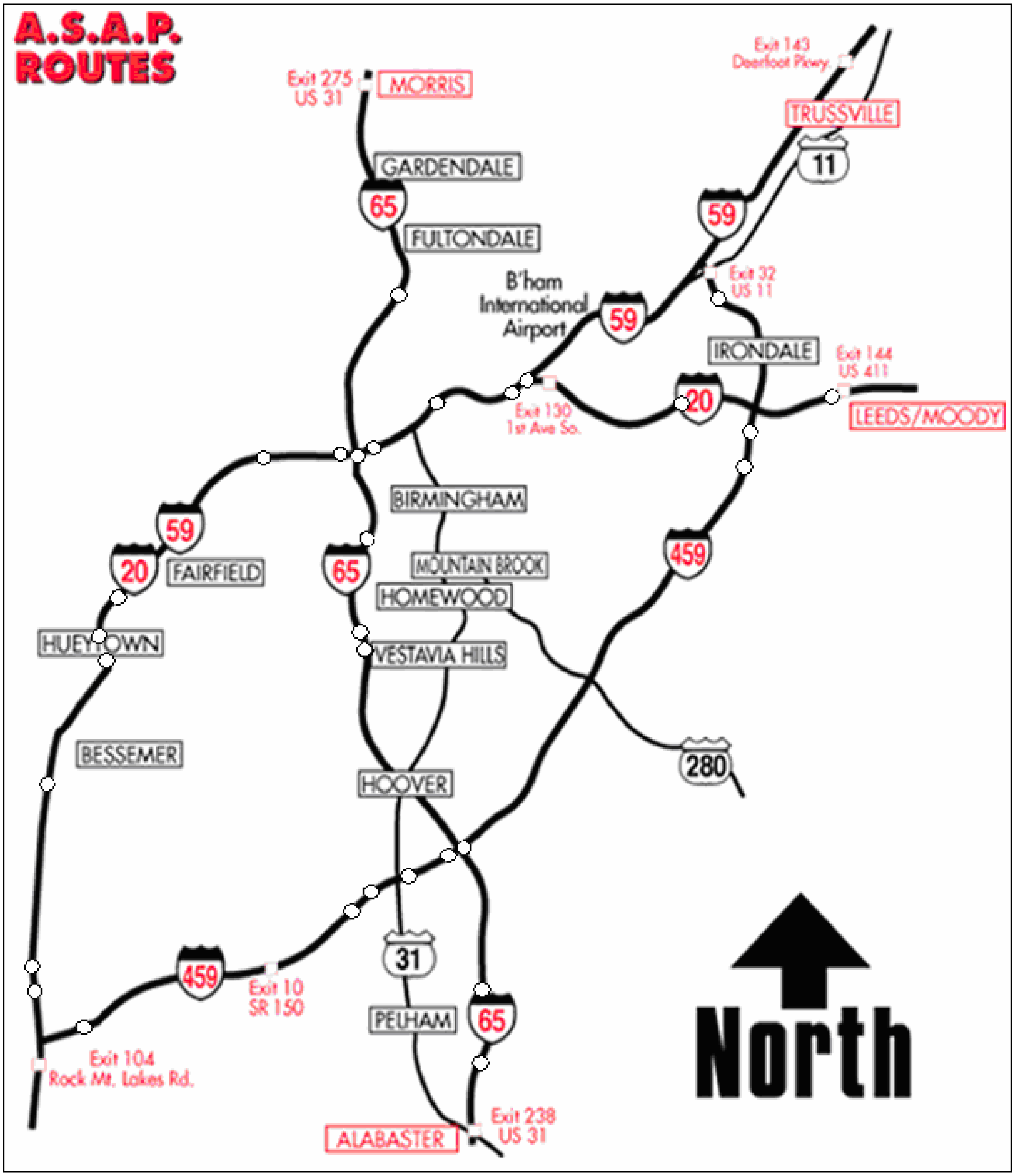

Figure 3-4: Spatial Distribution of Incident Locations

Within CORSIM, shoulder incidents were simulated as a 500 foot capacity-reduced, or "rubber-necking", section applied to all lanes of a particular network link. The one and two-lane blocked were simulated as a 500 foot rubber-necking section applied to all lanes, followed by a 300 foot blocked section with capacity reduction, and finally an additional 200 foot rubber-necking section applied to all lanes. These sections were simulated on the particular links determined through random number generation. Due to the short lengths of links 168,169 and 154,155, these two shoulder scenarios were simulated as a 300 foot capacity-reduced section. This shorter section allowed for the entire incident to occur within that particular link. The appropriate capacity reduction factors were obtained from Highway Capacity Manual Exhibit 22-6 (HCM, 2000). The exhibit is shown as Table 3-5.

Table 3-5: Highway Capacity Manual Exhibit 22-6 (HCM, 2000)

Number of Freeway Lanes by Direction	Shoulder Disablement	Shoulder Accident	One Lane Blocked	Two Lanes Blocked	Three Lanes Blocked
2	0.95	0.81	0.35	0.00	N/A
3	0.99	0.83	0.49	0.17	0.00
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.40	0.20
6	0.99	0.89	0.71	0.50	0.26
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	0.63	0.41

The shoulder incident simulations were modeled as 5000 second simulations whereas the one-lane and two-lane blocked simulations were modeled as 6200 second simulations. The actual incidents were stipulated to occur 15 minutes into the simulation to allow for the network to reach an initial steady-state. Similarly, 30 minutes of additional simulation time are included after the incident duration period is over to allow for complete clearance and a return to normal conditions. The additional 1200 seconds are required for the one-lane and two-lane blocked scenarios to account for the increased incident duration times as seen through the ASAP logbooks.

To ensure that each CORSIM network was appropriately constructed, localized volumes and speeds were observed within the simulation output. These numbers were examined to ensure consistency with "real" conditions. Although actual volume and speed numbers were not available for the entire Birmingham network, sound engineering judgment was applicable for this process. For example, situations in which the network produced clearly erroneous speeds (negative values or zero values) or volumes were further examined and the necessary adjustments were made to the network. These situations were most often encountered as a result of data entry error.

3.3 Sensitivity Analysis

Calculating potential benefits through incident management relies upon several inputs that in themselves have high inherent variability. It is virtually impossible to label one single value as an exact benefit due to the erratic nature of traffic behavior. Therefore, to capture this variability, this project has taken a series of snapshots of the ASAP program in action through varied CORSIM simulations. With a large enough dataset, the series appropriately describes a range of benefit numbers to a high degree of confidence as shown through the Central Limit Theorem. As stated, construction of this series relies upon conducting multiple simulation runs to address temporal and spatial variations and changing the incident duration, value of travel time, and vehicle occupancy inputs.

3.3.1 CORSIM Simulations

Each individual scenario stated was run within CORSIM eight times for statistical effectiveness. These 8 separate runs were performed in the exact same manner as each other but with a different internal random seed number within CORSIM creating 8 unique cases. The average delay values of the 8 runs for each scenario were then used to continue on with the sensitivity analysis.

A total of 8 separate runs were chosen as a recommendation from the Traffic Analysis Toolbox. Table 8 within the Toolbox provides multiple run recommendations that correspond to specific levels of precision within the CORSIM results. With a desired precision range of results set at 2.0, as measured by the desired confidence interval divided by the standard deviation, and a desired confidence level of 95%, the Traffic Analysis Toolbox recommends a minimum of 8 repetitions. This level of precision indicates that there is a 95% chance that the average output of the 8 repetitions falls within one standard deviation of the true mean. This level of precision was determined to be acceptable for this study. Table 3-6 illustrates the complete table of recommendations as taken from the Traffic Analysis Toolbox (FHWA, 2004).

Table 3-6: Traffic Analysis Toolbox Multiple Runs Recommendations(FWHA,2004)

Desired Range (CI/S)	Desired Confidence Level	Minimum Repetitions
0.5	99%	130
0.5	95%	80
0.5	90%	64
1.0	99%	36
1.0	95%	23
1.0	90%	18
1.5	99%	18
1.5	95%	12
1.5	90%	9
2.0	99%	12
2.0	**95%**	**8**
2.0	90%	6

3.3.2 Incident Duration

The large amount of information published citing reductions in incident duration with the assistance of a service patrol creates extensive insight in establishing an effective range that captures the possible variability within this input. As shown, average incident durations were reduced by as little as 5 minutes and as high as 25 minutes with the assistance of the service patrol. All of the studies considered found total incident duration reduction numbers within this range. 5 minute increments between the 5 and 25 minute range were deemed adequate in capturing the variability found within this aspect of service patrol benefits. This analysis created 5 distinct benefit/cost cases relating to 5, 10, 15, 20 and 25 minute reductions.

This project utilized incident duration lengths consistent with those of work already performed on this particular program. Calculated assumptions were made based upon the 2004-2005 ASAP logbooks and current literature in establishing base incident durations for both ASAP assistance and no-assistance. Over 900 incidents were examined in the ASAP logbooks to determine total incident duration. Although over 17,000 incidents are recorded within the available ASAP logbooks, only the 900 contained the necessary ASAP dispatch time to calculate total incident duration. It should be noted that the total incident duration consists of the entire length of time between the initial incident occurrence and ASAP departure.

For shoulder incidents, a maximum incident duration of 53 minutes was assumed without-ASAP assistance as compared to a low 28 minutes with-ASAP assistance. Similarly, a without-ASAP incident duration of 59 minutes was assumed for one-lane blocked incidents and a 34 minute incident duration was assumed with-ASAP assistance. Finally, a without-ASAP incident duration of 63 minutes was assumed for two-lane blocked incidents and a 38 minute incident duration was assumed with-ASAP assistance. As these duration lengths are taken with ASAP assistance, they underestimate the true unassisted average incident duration lengths. However, as this data is not available, the ASAP logbooks were viewed as the best possible source for this information. This assumption is acceptable as the measure of effectiveness for this program focuses on the reductions in incident duration length, not the incident duration length itself.

To account for shorter duration reductions, CORSIM runs were performed with the appropriate duration values specified. Table 3-7 illustrates the incident durations examined. The longest duration value was considered to represent the without-ASAP case for each type of incident. Similarly, the shorter duration values were used to emulate ASAP assistance and varying duration reductions. This process was performed for all 30 unique incident scenarios listed in Table 3-4. As stated, each simulation was performed a minimum of 8 times for all 6 incident duration times to create a grand total of 1440 (30 scenarios x 8 runs x 6 durations) runs within the CORSIM software. However, the average of each of the 8 separate runs was taken for use in the additional post-processing sensitivity analysis. This procedure produced 180 measures of total time traveled (vehicle-hours) to be further examined.

Table 3-7: Variable Incident Durations

Duration Reduction	Shoulder Incident		One-Lane Blocked Incident		Two-Lane Blocked Incident	
	w/ASAP	w/o ASAP	w/ASAP	w/o ASAP	w/ASAP	w/o ASAP
5 min	48	53	54	59	58	63
10 min	43	53	49	59	53	63
15 min	38	53	44	59	48	63
20 min	33	53	39	59	43	63
25 min	28	53	34	59	38	63

This project is interested in examining the potential impact of the ASAP program upon reducing delay by simulating different incident durations. Analyzing the impact of the ASAP program was performed by comparing the various “with-ASAP” values to the single “without-ASAP” value. Through this procedure, 5 unique impacts were calculated over 30 different scenarios creating 150 estimations of the effect of ASAP assistance.

3.3.3 Travel Time Values

Due to the variability associated with socio-economic studies, estimating the value of travel time was an obvious choice for inclusion within the sensitivity analysis. This input can have a large effect upon potential benefits of incident management programs as it controls the estimated time worth of those individuals delayed by the incident. Assumed values of travel time range between a low of $6/hr per passenger released by the American Automobile Association in 1987 to a high of $17.23/hr per passenger released by the Bureau of Labor Statistics for Georgia in 2005. The same study released a value of $15.54/hr for the state of Alabama. Bringing the $6/hr forward to 2005 dollars through the use of the consumer price index (CPI) refines the range from a low value of $9.72 to a high of $17.23. All other values considered fell within the range of $10/hr to $15/hr per passenger. Based upon these findings and engineering judgment, a sensitivity analysis was performed using values of $8/hr, $10/hr, $12/hr, $14/hr, and $16/hr per passenger. The CPI adjustment is described as equation 2-1.

Under a similar notion, the values of travel time for trucks must be considered. Based upon previous work on this project, a uniform 15% trucks was assumed on a network-wide basis. This assumption was included within these particular CORSIM runs. The literature review discovered truck travel time values ranging from a low of $26.87/hr in 1987 ($43.52 in 2003 with CPI adjustment) released by the American Automobile Association to a high of $72.65/hr in 2003 released by the Texas Transportation Institute. Following a similar method, five values of $30/hr, $40/hr, $50/hr, $60/hr, and $70/hr per truck were selected.

With the exception of the values obtained from the Georgia Navigator study, all of the other reports examined in the literature review revealed a common trend of assuming lower passenger car travel time values in conjunction with lower truck travel time values. Similarly, studies that assumed higher passenger car travel time values assumed higher truck travel time values. For example, the studies conducted in Florida and the Puget Sound region both applied relatively high values of $13.75/hr per passenger car and $72.65/hr per truck whereas the Hoosier Helper program in Indiana used lower numbers of $9.72/hr per passenger car and $26.87/hr per truck.

Based upon this general trend, the 5 unique passenger car travel time values and 5 unique truck travel time values were combined to create 5 combinations of travel time values that can be applied to each specific CORSIM scenario. The five combinations were grouped from the lowest to highest values with $8/hr per passenger car grouped with $30/hr per truck and $16/hr passenger car grouped with $70/hr per truck. The intermediate values were similarly grouped.

The 5 combination values were based upon 85% passenger cars and 15% heavy trucks. A simple calculation provided weighted travel time values of $11.3/hr, $14.5/hr, $17.7/hr, $20.9/hr, and $24.1/hr. These weighted values were applied to the entire traffic stream as a whole.

A total of 150 CORSIM scenarios average impact values and 5 travel time value combinations raised the number of calculated benefit figures to 750.

3.3.4 Average Vehicle Occupancy

In addition to travel time values, large variability is inherent within traffic flows when examining vehicle occupancy. This input can also have a large effect upon potential benefits of incident management programs as it controls the number of individuals affected by the incident. As presented in Chapter 2, the literature review discovered that average vehicle occupancies ranged from a low of 1.07 passengers per vehicle in Birmingham, Alabama to a high of 1.2 passengers per vehicle utilized as part of the FIRST program evaluation in Minnesota. Based upon these numbers, the small range of 1.0 to 1.2 passengers per vehicle was deemed adequate to capture the total variability found within this input. Six unique benefit/cost scenarios were created relating to the incremental vehicle occupancy numbers of 1.0, 1.04, 1.08, 1.12, 1.16, and 1.20 passengers per vehicle.

6 unique vehicle occupancy values created an additional 6 possibilities that can be applied to each specific CORSIM output. A total of 150 CORSIM scenarios, 5 possible travel time value combinations, and 6 vehicle occupancy raised the number of calculated benefit figures from 750 to 4500.

As shown, the variation of each of these parameters created an extremely large number of possible combinations of inputs for each CORSIM scenario. Based upon this large number of combinations, 4,500 unique benefit figures were calculated for the ASAP program. Due to the large amount of figures calculated through this analysis, informative benefit ranges were effectively obtained.

3.4 Total Benefit Calculations

Calculation of potential benefits was a simple cross-classification multiplication procedure performed in Microsoft Excel. Each of the 150 separate differences was multiplied by every combination of travel time value and vehicle occupancy value to create the 4,500 unique estimates from a single assist of the ASAP service. Equation 3-5 represents this cross-classification procedure.

$$Benefit(\$) = (CORSIMOutput(veh * hrs)) * \left(TravelTimeValue\left(\frac{\$}{pass * hr}\right)\right) * \left(Occupancy\left(\frac{pass}{veh}\right)\right) \quad (3\text{-}5)$$

Once more, the entire series of benefit estimates provides an appropriate range of values that was used to estimate real benefit to a high degree of confidence.

This range of values was applied throughout the entire 2005 year through examination of ASAP logbooks. A total yearly benefit estimate of the ASAP program was calculated by multiplying the range of benefit values calculated for a single incident by the total number of assists per year. These total yearly benefit estimates were then compared to a calculated 2005 ASAP program annual cost to calculate a range of benefit/cost ratios.

It should be noted that all 30 scenarios examined are simulating ASAP assistance on a Thursday. These scenarios do not consider Monday and Friday traffic behavior in which higher volumes might be expected. These higher volumes could create more significant delay savings and increase benefits. Disregarding Monday and Friday situations could skew the found benefit results in a conservative manner.

3.5 Total Cost Calculations

A freeway service patrol deployment has inherent costs associated with its operation. These costs are incurred through operations and maintenance of the program along with wages for employees. The Alabama Department of Transportation was contacted to provide information regarding the annual cost for the ASAP program. The most recent cost data able to be obtained dates back to 1997 in an unpublished study conducted at Auburn University in 2003. This study projected the ASAP annual costs out to a twenty year horizon. These cost data include 5 ASAP patrol vehicles, operating equipment, and salary for five operators and one supervisor. The study applied a four percent assumed growth rate to the 1997 figure to obtain an appropriate 2005 cost amount. Naturally, these cost data are significantly lower than the real cost data for 2005 as the program went through significant growth during that time. The ASAP program grew from five patrol vehicles and operators in 1997 up to 10 patrol vehicles and 18 operators in 2005. These cost data are consistent with previous studies performed on the ASAP program.

It should be noted that actual cost data from 2005 would be much more desirable as opposed to this method discussed. A four percent standard growth rate may not accurately portray the expansion of the ASAP program. Unfortunately, 2005 cost data were not able to be obtained despite numerous attempts to do so. The lower cost data will create higher benefit/cost ratios than should be apparent and will provide unconservative results. Nevertheless, these older data can provide approximate benefit/cost ratios that illustrate the effectiveness of the ASAP program.

3.6 Benefit/Cost Calculations

This ratio is easily calculated by dividing the total annual benefit by the annual yearly cost. A benefit/cost ratio provides an effective and easily understood method that relates the performance and importance of the ASAP program to the general public. Again, the benefit/cost ratio calculated for this project only considers mobility related benefits. Additional benefits with regards to the environment, safety, and direct customer services are beyond the scope of this report.

CHAPTER FOUR

RESULTS

The purpose of this chapter is to present the results of the sensitivity analysis for the Alabama Service and Assistance Patrol detailed in Chapter 3. In addition, this chapter presents further analysis that illustrates how these results were applied in calculating an average range of potential mobility benefits. This information is compared to the most recent ALDOT cost data available to reveal an average annual benefit/cost range for the program. These benefit figures only represent mobility savings and do not address other aspects of the program regarding safety and emissions reductions.

30 separate incident scenarios were simulated within the CORSIM program in an attempt to analyze the potential impact of the ASAP program on Birmingham highways. 180 unique values of total time traveled (vehicle-hours) were calculated by simulating each of the 30 scenarios with 6 different incident durations. 150 unique difference vehicle-hour values were calculated that illustrate the impact of ASAP assistance through direct subtraction of the "without-ASAP" cases from the "with-ASAP" cases considered. In addition, a cross-classification procedure was conducted in multiplying the 150 vehicle-hours of travel values by 5 different travel time values and 6 different vehicle occupancy values. This procedure created 4,500 dollar amounts that represent the potential range of mobility benefits of a single assist from the ASAP service. This process is presented in detail in Chapter 3.

This chapter reports the direct outputs from the CORSIM program as well as the calculated differences discussed due to ASAP assistance. In addition, total benefit calculations are presented through the cross-classification procedure previously shown in Chapter 3. These calculated benefits are expanded to total annual benefits through consultation of the ASAP logbooks. Finally, total cost calculations were incorporated to calculate benefit/cost ratios. Based upon this information, a reasonable range of the benefit/cost for the ASAP program can be estimated for an entire year of operation.

4.1 CORSIM Output

CORSIM provides a detailed output file that explains the simulated model. This file contains information at both the local and global scale. The local information reveals the small-scale details of the network on a link-by-link basis. These data include measures of volumes, travel speeds, average speed, delay time, emissions reports, etc. Similarly, the global output contains the same basic information on a network-wide scale. Within this study, the difference in total network travel time was selected as the measure of effectiveness to analyze the impact of ASAP assistance. The average hourly total time for the eight simulation runs for each of the six variations of all thirty models considered are found in Table 4-1. In addition, Table 4-2 illustrates the corresponding 150 calculated differences between the "without-ASAP" assistance column and "with-ASAP" assistance columns. Again, these differences reveal the impact of ASAP assistance as a function of varying incident durations. The positive hourly differences indicate delay savings due to the ASAP assistance. Conversely, the negative hourly differences indicate increased delay. The presence of negative differences is described in detail later in this chapter.

Table 4-1: Network Wide Travel Times as a Function of Incident Duration Reductions

				Incident Duration Reduction "with" ASAP Average Network-Wide Travel Time (Veh-Hrs)				
#	Incident Time	Incident Type	"without" ASAP	5min	10min	15min	20min	25min
Scenario 1	8 am - 9 am	1-Lane	18351	18350	18362	18362	18371	18305
Scenario 2	4 pm -5 pm	Shoulder	16355	16353	16343	16348	16346	16347
Scenario 3	4 pm -5 pm	Shoulder	16373	16375	16373	16366	16315	16376
Scenario 4	3 pm - 4 pm	Shoulder	14770	14772	14767	14760	14744	14754
Scenario 5	7am - 8 am	1-Lane	25175	25166	25164	25096	25123	25125
Scenario 6	10 am -11am	Shoulder	10151	10148	10153	10160	10152	10162
Scenario 7	5 pm- 6 pm	2-Lanes	21447	21420	21426	21414	21379	21408
Scenario 8	4 pm - 5 pm	Shoulder	16380	16377	16383	16382	16381	16411
Scenario 9	9 pm -10 pm	Shoulder	5909	5910	5916	5911	5911	5911
Scenario 10	12 pm -1 pm	Shoulder	11065	11069	11069	11066	11062	11064
Scenario 11	10 am - 11 am	Shoulder	10157	10158	10164	10151	10156	10157
Scenario 12	11 am - 12 pm	Shoulder	10573	10576	10572	10584	10577	10568
Scenario 13	6 am - 7 am	1-Lane	16637	16559	16504	16391	16250	16183
Scenario 14	6 pm - 7 pm	Shoulder	11642	11637	11641	11644	11646	11658
Scenario 15	6 pm - 7 pm	Shoulder	11671	11669	11669	11672	11660	11656
Scenario 16	7 pm - 8 pm	Shoulder	8268	8268	8266	8274	8274	8269
Scenario 17	9 pm - 10 pm	Shoulder	5918	5916	5915	5917	5909	5909
Scenario 18	2 pm - 3 pm	Shoulder	12457	12459	12464	12464	12468	12465
Scenario 19	6 pm - 7 pm	Shoulder	11655	11652	11649	11637	11657	11647
Scenario 20	8 pm - 9 pm	Shoulder	6877	6876	6880	6896	6891	6889
Scenario 21	8 am - 9 am	Shoulder	14238	14239	14231	14218	14212	14224
Scenario 22	5 pm - 6 pm	Shoulder	16720	16724	16722	16727	16721	16736
Scenario 23	5 pm - 6 pm	2-Lanes	21430	21412	21381	21362	21405	21329
Scenario 24	7 pm - 8 pm	1-Lane	10518	10478	10443	10433	10400	10366
Scenario 25	8 pm - 9 pm	Shoulder	6888	6892	6891	6884	6885	6890
Scenario 26	2 pm - 3 pm	Shoulder	12459	12454	12463	12453	12461	12460
Scenario 27	2 pm - 3 pm	Shoulder	12491	12494	12494	12494	12487	12488
Scenario 28	11 am - 12 pm	Shoulder	10582	10580	10577	10582	10588	10582
Scenario 29	7 am - 8 am	Shoulder	18941	18952	18937	18958	18941	18940
Scenario 30	7 am - 8 am	Shoulder	18983	18991	18988	18999	18998	18959

Table 4-2: Difference in Network-Wide Travel Times as a Function of Incident Duration Reductions

	Incident Duration Reduction Average Difference in Network-Wide Travel Time (Veh-Hrs)				
#	5min	10min	15min	20min	25min
Scenario 1	1	-11	-10	-19	46
Scenario 2	2	12	7	9	8
Scenario 3	-2	0	7	58	-3
Scenario 4	-1	30	10	27	17
Scenario 5	9	11	79	52	50
Scenario 6	3	-2	-9	-2	-12
Scenario 7	27	21	33	68	39
Scenario 8	3	-3	-2	-1	-31
Scenario 9	-1	-7	-2	-2	-2
Scenario 10	-4	-4	-1	3	1
Scenario 11	-1	-7	7	1	0
Scenario 12	-3	1	-11	-4	5
Scenario 13	77	133	246	387	454
Scenario 14	4	0	-2	-4	-16
Scenario 15	2	2	-1	12	15
Scenario 16	0	2	-5	-6	0
Scenario 17	3	4	2	10	9
Scenario 18	-3	-7	-7	-12	-8
Scenario 19	2	5	17	-2	8
Scenario 20	1	-3	-19	-14	-13
Scenario 21	-1	7	20	26	13
Scenario 22	-4	-1	-7	-1	-16
Scenario 23	18	48	68	25	101
Scenario 24	40	75	85	118	151
Scenario 25	-4	-3	4	3	-2
Scenario 26	5	-3	6	-2	-1
Scenario 27	-4	-3	-3	4	3
Scenario 28	2	5	0	-5	0
Scenario 29	-11	4	-17	1	1
Scenario 30	-8	-5	-15	-14	25

Again, each data entry in Table 4-1 represents the average output for all 8 repetitions conducted on each scenario. Conversely, the data entries in Table 4-2 present the average hourly difference of all 8 repetitions between the "without-ASAP" variation and the 5 "with-ASAP" variations. The five "with-ASAP" variations differ in regards to incident duration reduction. As each result represents the average of an eight run sample, the "without-ASAP" results and corresponding "with-ASAP" results can be compared using statistical methods. To determine statistical significance between each sample, two-sample t-tests were performed upon each set of network-wide travel time results for all thirty scenarios. These t-tests compared the "without-ASAP" results against each incident reduction. The null hypothesis of these t-tests states that the means of the two data sets are equal. These significant differences were calculated with a 95% significance level. Calculated p-values that fall above this confidence level indicate a failure to reject the null hypothesis and no statistically significant difference. However, calculated p-values below this significance level indicate that the null hypothesis should be rejected. This rejection indicates a statistically significant difference between the two data sets. A statistically significant difference reveals that the ASAP assistance is having a significant impact upon delay. The null hypothesis and alternative hypothesis for a two-sample t-test are presented as equations 4-1 and 4-2. The results from these two sample t-tests are attached as Appendix A.

$$H_0 : \mu_1 = \mu_2 \tag{4-1}$$

$$H_a : \mu_1 \neq \mu_2 \tag{4-2}$$

As the difference in means were relatively small with regards to the size of the raw data, only two scenarios presented statistically significant differences. However, a few other scenarios presented differences that may have a "practical", but not significant, impact. Although these practical differences are not statistically different, they are large enough to dramatically influence the results of this project and must be equally considered. Three other scenarios revealed "practically" different results that should be given the same consideration as the two statistically different results sets.

Table 4-3 presents both statistically different results and deemed "practically" different results. Of these five scenarios, only scenarios 13 and 24 were significantly different with regards to t-statistics. Scenarios 5, 7, and 23 contained results that were labeled as practically different. These 5 scenarios represent both 2-lane blocked simulations and three of the four 1-lane blocked simulations. It is not surprising to see that the more severe incidents were those in which ASAP presented a clear positive impact.

Table 4-3: Statistically Different and Practically Different Results

Incident Duration Reduction					
#	5min	10min	15min	20min	25min
Scenario 5	9	11	79	52	50
Scenario 7	27	21	33	68	39
Scenario 13	77	133	246	387	454
Scenario 23	18	48	68	25	101
Scenario 24	40	75	85	118	151

In examining the remaining scenarios, it is plain to see that the differences in network-wide travel times as reported by CORSIM (Table 4-2) are quite "noisy". This "noise" can be attributed to the random seed generation within CORSIM. It was due to this reason that each scenario was run 8 separate times.

The remaining 25 scenarios that did not have statistically or practically significant results do not appear to have any discernable trend within the data after averaging these eight runs. As a result, both positive and negative differences were attributed to random seed generation and not ASAP impact. The small variations in the data can be viewed as similar to the differences generated during a Monte Carlo simulation. Based on this theory, the small variations within the results would diminish with an increased amount of runs. To test this idea, Scenario 10 was run 30 separate times. This larger data set was considered to filter out the noise found with a smaller pool of results and to confirm the impact of the random seed generation.

When Scenario 10 was conducted 30 separate times as opposed to the original eight, the small variations in results were reduced. In addition, the standard deviation of the results was lessened. These results confirm the impact of the random seed generation upon the variations of the found results. Table 4-4 presents the total vehicle time averaged over both 8 runs and 30 runs for Scenario 10. In addition, the corresponding standard deviations are presented. Figure 4-1 graphically illustrates this information. This process illustrates why some of the CORSIM results indicated increased delay with ASAP assistance as represented by a negative hourly difference in Table 4-2. This increased delay was generated through the random seed generation of the program and not by ASAP. Based upon the results of this process, the 25 scenarios that were not deemed to be statistically or practically different are not believed to contribute either detriment or beneficial impact from the ASAP program.

Although conducting Scenario 10 thirty times as opposed to eight revealed more consistent results; in general, eight repetitions appears to be adequate to determine where ASAP assistance is creating significant results. As shown in Table 4-4, the average vehicle-hours of travel time and corresponding standard deviations underwent very small changes with the addition of 22 extra runs. These small changes are not considered large enough to justify the extra resources needed to examine all thirty scenarios with thirty repetitions.

Table 4-4: Total Vehicle Times and Standard Deviations of Scenario 10

Scenario 10						
Incident Duration (min)	28	33	38	43	48	53
Average Veh. Time, 8 runs (Veh-Hrs)	11064	11062	11066	11069	11069	11065
Average Veh. Time, 30 runs (Veh-Hrs)	11059	11058	11059	11058	11057	11058
Standard Deviation, 8 runs	31.59	44.86	36.67	44.74	42.13	49.14
Standard Deviation, 30 runs	25.52	31.88	32.27	42.66	39.52	39.45

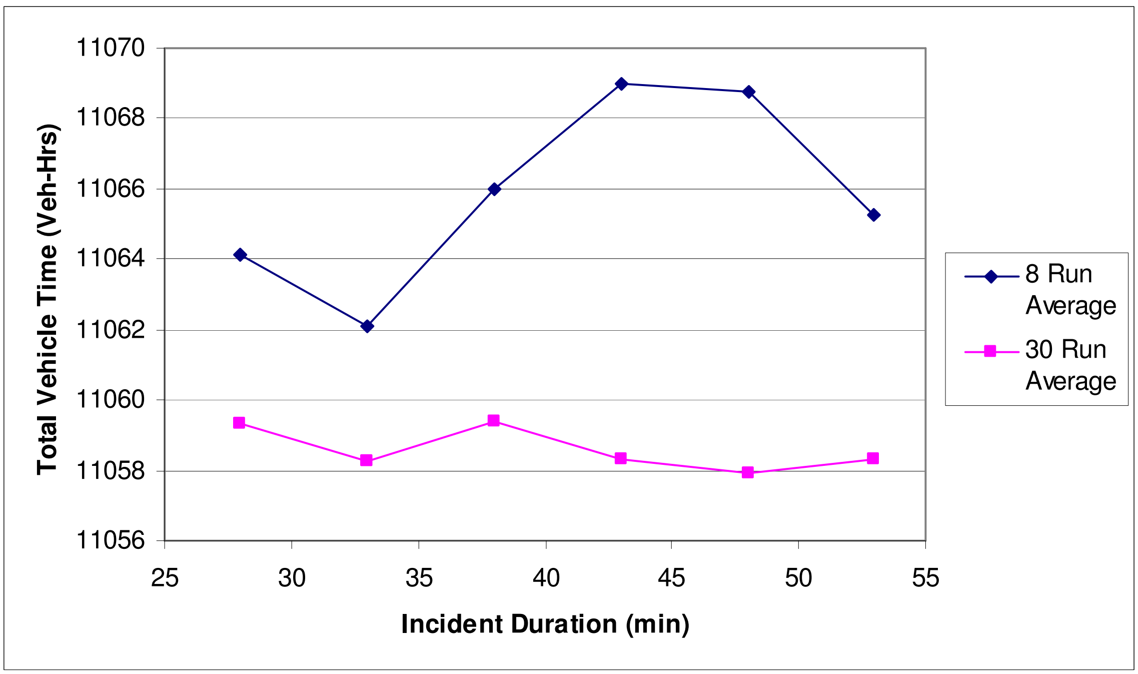

Figure 4-1: "Noise" Reduction of Scenario 10

When considering all 30 scenarios as a whole, the “noise” surrounding the data on an individual basis is dropped and a clear trend emerges. The larger data pool reduces the effect of the random seed generation. In looking at all 30 scenarios together, the ASAP program created almost uniformly increasing delay reductions with increasing incident duration reductions. This trend is consistent from reducing delay by an average of 5.11 vehicle-hours for a 5-minute duration reduction up to 28.08 vehicle-hours for a 25-minute duration reduction. Table 4-5 presents the average difference in travel time for all thirty scenarios as a function of incident duration reduction. These data are graphically illustrated as Figure 4-2.

Table 4-5: Average Difference in Total Time as a Function of Incident Duration Reduction

Incident Duration Reduction				
5min	10min	15min	20min	25min
5.11	9.19	15.97	23.82	28.08
Reporting Difference in Network-Wide Travel Time (Veh-Hrs)				

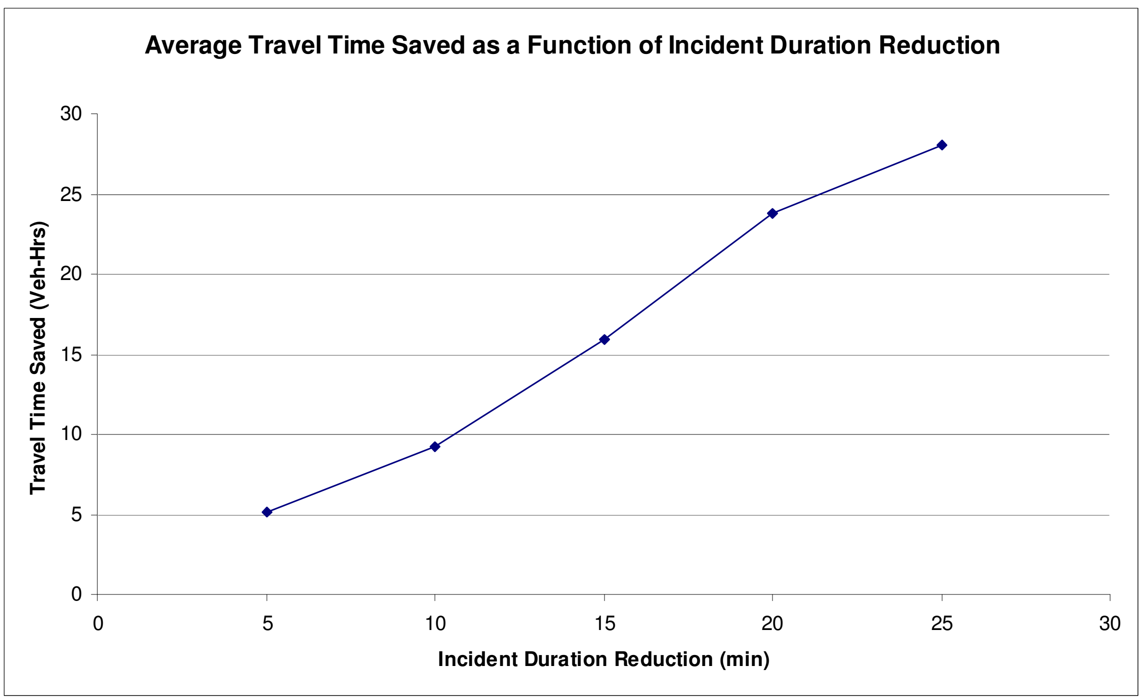

Figure 4-2: Average Travel Time Saved as a Function of Incident Duration Reduction

A deeper examination of the 25 scenarios without practical or statistically significant results reveals that 24 of the 25 are shoulder scenarios. This result was expected for the off-peak incidents. As stated, shoulder incidents were simulated as a reduced capacity section as recommended by the Traffic Analysis Toolbox. For off-peak hours, the reduced capacity was not severe enough to drop the level of service of the highway. Therefore, an incident will not create delay due to capacity reduction.

Exhibit 22-3 of the Highway Capacity Manual, that details flow versus speed, illustrates how a small reduction of capacity can have a negligible effect upon speeds. Figure 4-3 illustrates this exhibit from the Highway Capacity Manual (2000). As an example, a 15% capacity reduction essentially shifts the entire figure to the left; however, if the flow is not large enough then speeds will not be reduced. The flow will still be small enough to fall on the horizontal top portion of the curve.

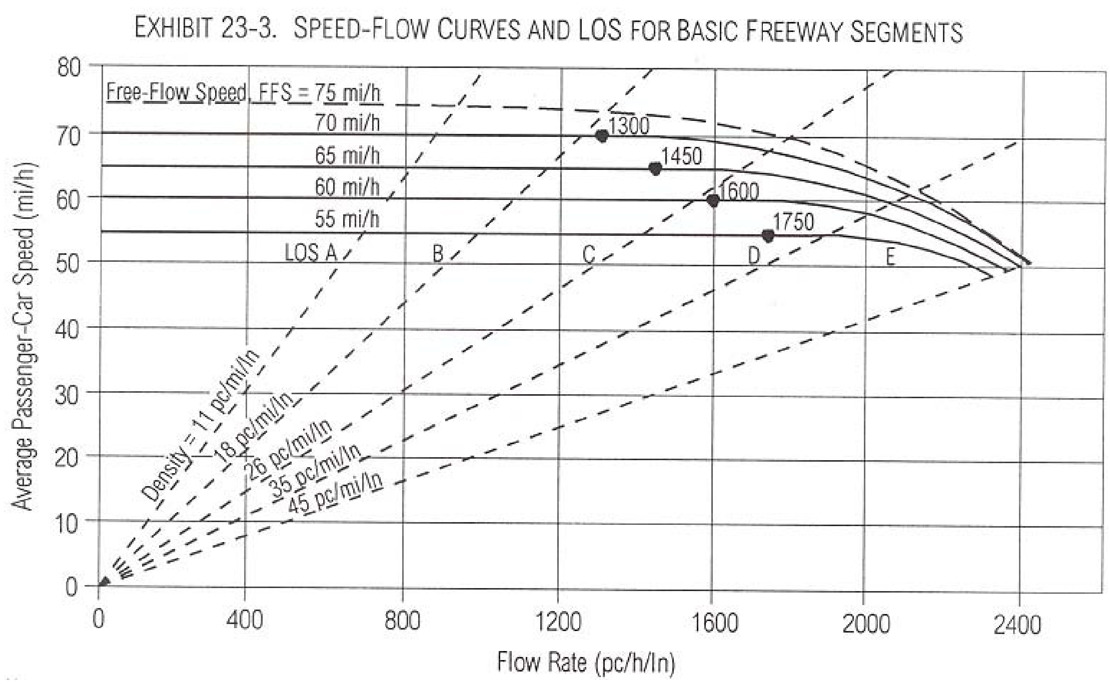

Figure 4-3: Highway Capacity Manual Speed/Flow Model, Exhibit 23-3 (HCM, 2000).

The remaining peak-hour incidents and 1-lane incident did not create a discernable trend in delay reduction due to the prevalence of recurring congestion within the network. This typical congestion masks the effect of ASAP assistance with already prevalent delay.

Although 25 of the 30 considered scenarios did not reveal any significant positive or negative impact, the remaining 5 scenarios far outweighed the others to create uniform and increasing delay reduction over all 5 delay reductions. These delay reductions generate monetary benefits through cross-classification with the other inputs considered.

4.2 Calculated Benefits

Dollar benefit amounts were calculated through a cross-classification procedure with the remaining two sensitivity analysis inputs discussed. The resultant travel time differences were multiplied by every combination of value for travel time and average vehicle occupancy. Equation 3-2 details the process of this procedure, whereas Table 4-6 illustrates one particular example. This table illustrates a possible range of benefits that were calculated for one of the differences found through ASAP assistance. This procedure was performed for all 150 calculated differences. These calculated benefits range from a low of $0 up to a high of $13,122. Averaging all 4500 calculated dollar amounts reveals an average program benefit of **$319.93** for a single assist. Figure 4-4 is a cumulative distribution function representing the entire range of benefits. This figure reveals that almost half of all the scenarios analyzed produced zero benefit with regards to mobility savings. In addition, only a very small percentage of the scenarios analyzed produced large dollar savings as indicated by the pronounced upper tail.

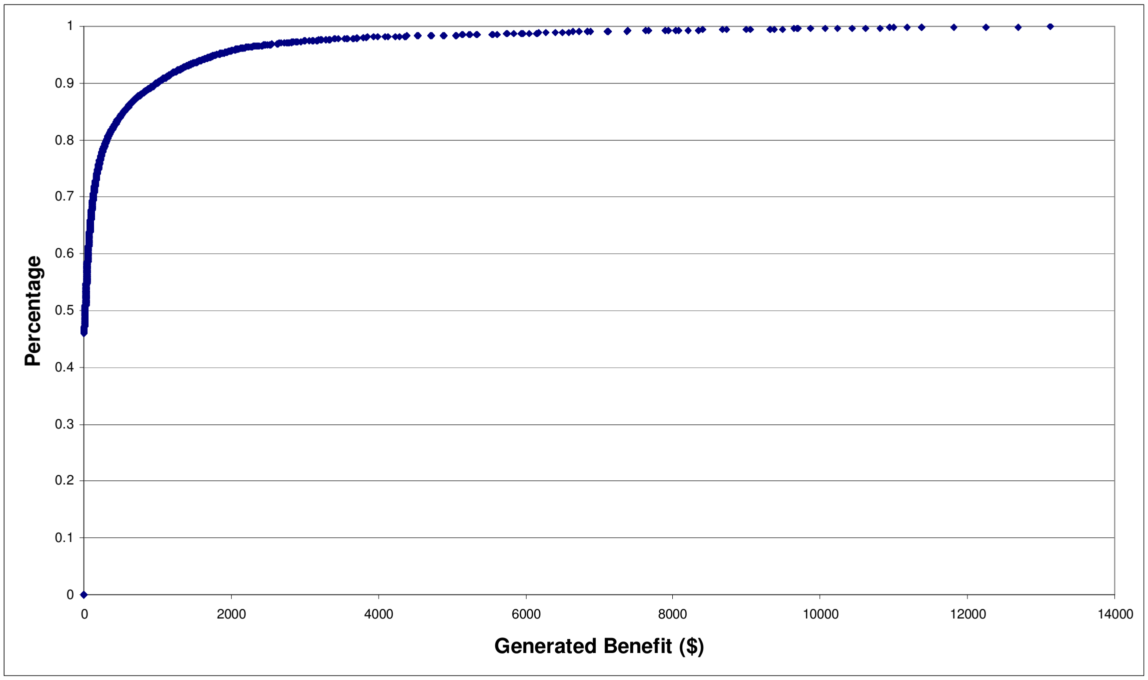

Figure 4-4: Generated Benefit Cumulative Distribution Function

Table 4-6: Cross-Classification Example Procedure for Scenario 5, 20 minute Duration Reduction

	Average Vehicle Occupancy Benefit Dollars ($)					
Travel Time Value ($/hr)	1	1.04	1.08	1.12	1.16	1.2
11.3	302.27	314.36	326.45	338.54	350.63	362.73
14.5	387.87	403.3	418.90	434.42	449.93	465.45
17.7	473.47	492.41	511.35	530.29	549.23	568.17
20.9	559.07	581.43	603.80	626.16	648.52	670.89
24.1	644.67	670.46	696.24	722.03	747.82	773.61

Conducting the same procedure for the average differences in total time (Table 4-5) reveals an average benefit range of **$57.69** up to **$812.08** for a single assist. These figures include the results from all thirty scenarios examined. It is plain to see that these averages are heavily influenced by the few significant results shown in Table 4-3. Figure 4-5 depicts this average range of benefits calculated through the cross-classification procedure for each incident duration reduction. It is important to note that the average mobility savings are all positive and increase with increasing duration reductions. In addition, it is apparent that the range of potential savings also increases with increasing incident duration.

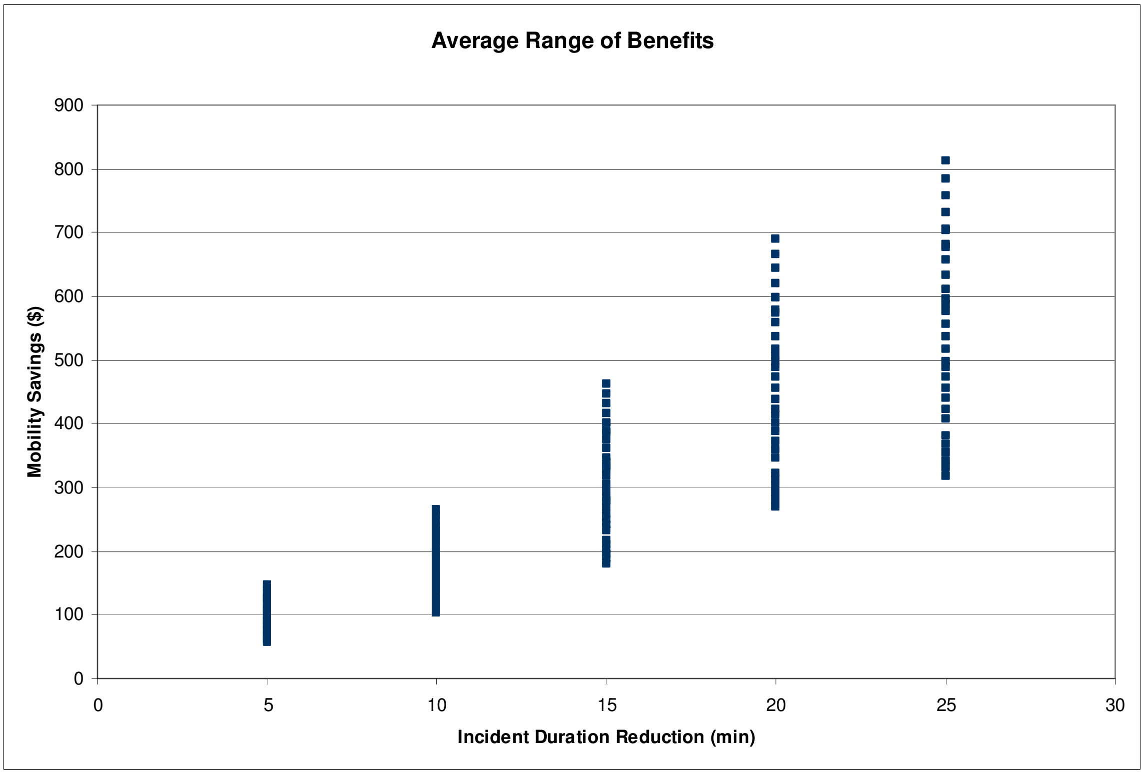

Figure 4-5: Average Mobility Savings

As related in Chapter 3, total yearly benefits were estimated by multiplying the average benefit range for a single assist by the total number of assists per year. Multiplication of the previously calculated range by 17,090 assists in the 2004-2005 year provides a total yearly benefit range of approximately **$985,900.00** to **$13,878,400.00**. The lower value of this range naturally represents a small value for travel time and low vehicle occupancy. Conversely, the upper value of this range represents a larger value of travel time and higher vehicle occupancy.

4.3 Total Benefit/Cost

As stated, an unpublished study at Auburn University, conducted in 2003, produced an extrapolated 2005 annual cost of $380,400. Details regarding the calculation of this figure are presented in Chapter 3. These cost data underestimate the true cost of the ASAP program in 2005 as the program has undergone terrific growth during those years. Unfortunately, these outdated data are the best available for this report. Based upon this underestimation, more recent cost data should continue to be pursued.

Although the cost data is known to be dated, it is important to produce an approximate range of benefit/cost ratios for this project to serve as an initial benchmark to measure performance. Benefit numbers by themselves carry relatively little weight without the corresponding cost figures available for comparison.

Using the benefit numbers presented in Section 4.2 and the cost figure discussed, a benefit/cost ratio range of **2.6:1** up to **36.5:1** was calculated for the ASAP program. This ratio range represents the annual systemwide mobility benefits, with respect to cost, during 2005. These calculated benefit/cost ratios indicate that ASAP is a cost-effective program with regards to incident management.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents conclusions drawn from this critical analysis of the ASAP program. In addition, recommendations for various improvements to the ASAP program are presented. Finally, recommendations for future research with regards to the ASAP program are also given.

5.1 Conclusions

This study has revealed that ASAP is a cost-effective program to help implement incident management within the Birmingham, Alabama interstate system. As shown in Chapter 4, the program was estimated to produce a range of benefits of $57.69 to $812.08 with an average value of $319.93 for a single assist with regards to mobility savings. These average values for a single assist were translated into an average annual systemwide benefit using the 17,090 total assists performed in 2005. A perceived annual benefit range of approximately $985,900.00 to $13,878,400.00 was calculated for the ASAP program. Using the best cost data available, a benefit/cost ratio range of 2.6:1 to 36.5:1 was found. In addition, based on the average value for a single assist, a most likely benefit/cost ratio of 14.4:1 was found. This range is consistent with previous published numbers regarding FSP services. As revealed in the literature review, a range of benefit/cost ratios of 2:1 to 41.5:1 was discovered. The benefit/cost ratios calculated for this study fall within these numbers, providing additional confidence in these results. In addition, a previous study performed on the ASAP program, using a limited number of incident scenarios, indicated a calculated benefit/cost ratio of 23.5:1 (Dixon, 2006). Again, this number falls within the range found in this study.

This large benefit range was determined as a result of the sensitivity analysis presented in Chapter 3. It is quite clear that varying the inputs of incident location, incident time, incident duration reduction, value of travel time, and vehicle occupancy can have a profound impact upon the perceived mobility benefits calculated. A sensitivity analysis of these variables appears to be an appropriate method for evaluating freeway service patrol organizations. It is apparent that proposing a single benefit value is a less appropriate method in analyzing these programs as opposed to analyzing a series of values based upon the large benefit/cost range found. This fact becomes even more apparent when examining the large number of assumptions that need to be made to arrive at a single number. A single benefit estimation may not paint a clear picture detailing exactly how well the FSP is performing due to overestimation or underestimation of more realistic benefit/cost ratios.

Although the benefit range is quite large, the results reveal that the ASAP program is extremely cost efficient when confronting non-recurrent congestion in the Birmingham area. This program consistently outweighs the corresponding annualized cost data by a significant margin regardless of which variables are chosen through the sensitivity analysis. This aspect of the results is extremely important. As the average benefit values are consistently positive, it provides assurance towards ALDOT that the program is being operated in a cost-effective manner.

5.2 Recommendations for ASAP

Although the ASAP program was found to be cost-effective in averaging all 30 scenarios examined, it is important to note that only 5 out of the 30 scenarios revealed statistically different and practically different results. All five of these scenarios were the more severe incidents with either one or two travel lanes blocked. 24 of the 25 scenarios that did not reveal significant results were simulated shoulder incidents. It is apparent that shoulder incidents have little effect upon traffic flow in the area. Based on these results, ASAP should reevaluate the priority given to incident assists. Initial priority should be given to the more severe incidents in which traffic lanes are blocked. These situations allow the patrol units to more effectively influence the traffic flow with regards to mobility benefits.

Although this project did not reveal any substantial positive benefits with shoulder assists, the ASAP program should not ignore these situations. The patrol unit can provide direct customer benefits towards the highway user making these assists worthwhile. Again, these direct benefits were not included within this analysis.

The ASAP program should consider a more organized method for record keeping. The ASAP logbooks considered for this project were severely lacking in data entry. Only five percent of the incidents during 2005 contained patrol unit departure times. This information was utilized to calculate the actual incident duration times used for this study as discussed in Chapter 3. More complete information would produce more accurate incident duration times and potentially narrow the range of incident duration reductions.

5.3 Recommendations for Future Research

The purpose of this project was to objectively analyze the cost-effectiveness of the ASAP program with respect to mobility benefits and its corresponding annualized cost. As the program was found to perform extremely well within the hours and mileage serviced, additional research should be performed to determine if an expansion of the program is worthwhile. Currently the ASAP service runs from 6 a.m. to 10 p.m. on Monday through Friday. This service could potentially be expanded to 24 hours a day and to include weekend hours. Testing an expansion of ASAP would follow a similar analysis as performed in this study. Separate networks would have to be calibrated within CORSIM to reflect early morning and weekend traffic conditions.

This project only considered the mobility savings found through ASAP assistance. Future studies should seek to examine the entire scope of benefits that the ASAP program can produce. These program-related benefits include environmental impacts through emissions reductions, safety enhancements through reduction of secondary crashes, and direct customer services to those in need. Similar evaluations with respect to these aspects of ASAP would allow the development of an all-encompassing range of true benefits that can be used to support funding of the program.

As previously stated in Chapter 3, the cost data utilized for the calculation of the benchmark benefit/cost ratios of this study is severely outdated. Future research efforts should seek to obtain more recent cost figures for the ASAP program. These updated figures would allow the calculation of more appropriate benefit/cost ratios detailing the performance of ASAP today.

REFERENCES

Alabama Department of Transportation. Alabama Traffic Statistics- 2005. Accessed: June 2007. http://aldotgis.dot.state.al.us/trafficvolume/viewer.htm

Alabama Service and Assistance Patrol. Alabama Department of Transportation. Accessed: June 2007. http://www.dot.state.al.us/Public_Info/ASAPQ&A.asp

Dixon, Luke R., "An Evaluation of the Alabama Service and Assistance Patrol with Respect to Mobility-Related Benefits." Auburn University, Master's Thesis, May 2007.

Dougald, Lance E., and Demetsky, Michael J., "Performance Analysis of Virginia's Safety Service Patrol Programs: A Case Study Approach." Virginia Transportation Research Council. Report No. VTRC 06-R33. June 2006. http://www.virginiadot.org/vtrc/main/online_reports/pdf/06-r33.pdf

Fambro, Daniel B., et. al., "Cost Effectiveness of Freeway Courtesy Patrols in Houston" Transporation Research Board, TRR 601, Washington D.C., 1976.

Fenno D. and Ogden, M., "Freeway Service Patrols: A State of the Practice." Transportation Research Record 1634, Transportation Research Board, National Research Council, Washington DC, 1998, pp 28-38.

"Traffic Analysis Toolbox Vol. IV: Guidelines for Applying CORSIM Microsimulation Modeling Software." FHWA, Publication No. FHWA-HOP-07-079. January 2007.

Georgia Department of Transportation. "Benefit Analysis for the Georgia Department of Transportation NaviGAtor Program." Project No. NH-7713-00(010), August, 2006.

Hagen, L., Zhou, H., and Singh, H., "Road Ranger Benefit Cost Analysis." Research Project Report for Center for Urban Transportation Research, University of South Florida, College of Engineering, November 2005.

Haghani, Ali, et. al. "Methodology for Quantifying the Cost Effectiveness of Freeway Service Patrol Programs." University of Maryland. February 2006.

Hawkins P. A., "Evaluation of the South West Freeway Motorist Assistance Program in Houston". Report No. TX-94/1922-IF, Texas Transportation Institute, College Station, Texas, 1993.

He, Harry. “Fwd: Re: Average Vehicle Occupancy.” Email to Rod Turochy. 1 Mar. 2007.

Highway Capacity Manual. Transportation Research Board. 2000.

Khattak, Asad J. and Rouphail, Nagui., “Incident Management Assistance Patrols: Assessment of Investment Benefits and Costs.” Carolina Transportation Program, Report No. FHWA/NC/2005-02, January, 2005.

Latoski S., Pal, R., and Sinha. K., “Cost Effectiveness Evaluation of Hoosier Helper Freeway Service Patrol.” Journal of Transportation Engineering, Volume 125, Issue 5, 1999, pp 429-438.

Ma, Yongchang, et. al., “Harnessing the Power of Microscopic Simulation to Evaluate Freeway Service Patrols.” Paper No. 07-3360, Transportation Research Board. August, 2006.

Minnesota Department of Transportation., “FIRST Program Evaluation”. Report Number A-MNDOT0452.00. November 2004. http://www.dot.state.mn.us/tmc/documents/FIRST-Program-Evaluation.pdf

Nee, Jennifer and Hallenback, Mark E., “Evaluation of the Service Patrol Program in the Puget Sound Region.” Washington State Transporation Center, Project No. T1803, Task 37, September 2001.

Schrank, D. and Lomax, T., “The 2005 Urban Mobility Report.” Texas Transportation Institute, The Texas A&M University System. May 2005. http://mobility.tamu.edu/ums/report/

Skarbadonis, Alexander, et. al., “Evaluation of the Freeway Service Patrol (FSP) in Los Angeles.” California PATH Research Report. UCB-ITS-PRR-98-31. September, 1998

Traffic Software Integrated System (TSIS) Version 5.1, Volume I. ITT Industries, Inc., Systems Division. February 2003.

APPENDIX

TWO SAMPLE T-TEST RESULTS

Scenario 1:

	w/o ASAP	*25min Reduction*
Mean	18351.25	18305.13
Variance	20453.07	14780.98
Observations	8.00	8.00
t Stat	-0.70	
P(T<=t) one-tail	0.25	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.50	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	18351.25	18361.88
Variance	20453.07	21480.41
Observations	8.00	8.00
t Stat	-0.15	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.89	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	18351.25	18370.63
Variance	20453.07	19667.41
Observations	8.00	8.00
t Stat	0.27	
P(T<=t) one-tail	0.39	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.79	
t Critical two-tail	2.14	

	w/o ASAP	*5 min Reduction*
Mean	18351.25	18349.88
Variance	20453.07	23959.84
Observations	8.00	8.00
t Stat	0.02	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.99	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	18351.25	18361.63
Variance	20453.07	24180.84
Observations	8.00	8.00
t Stat	-0.14	
P(T<=t) one-tail	0.45	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.89	
t Critical two-tail	2.14	

Scenario 2:

	w/o ASAP	*25min Reduction*
Mean	16354.88	16347.38
Variance	1082.41	2837.13
Observations	8.00	8.00
t Stat	0.34	
P(T<=t) one-tail	0.37	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.74	
t Critical two-tail	2.18	

	w/o ASAP	*10 min Reduction*
Mean	16354.88	16342.63
Variance	1082.41	1343.98
Observations	8.00	8.00
t Stat	0.70	
P(T<=t) one-tail	0.25	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.49	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	16354.88	16346.13
Variance	1082.41	2025.55
Observations	8.00	8.00
t Stat	0.44	
P(T<=t) one-tail	0.33	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.66	
t Critical two-tail	2.16	

	w/o ASAP	*5 min Reduction*
Mean	16354.88	16353.13
Variance	1082.41	653.84
Observations	8.00	8.00
t Stat	0.12	
P(T<=t) one-tail	0.45	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.91	
t Critical two-tail	2.16	

	w/o ASAP	*15 min Reduction*
Mean	16354.88	16347.63
Variance	1082.41	1894.27
Observations	8.00	8.00
t Stat	0.38	
P(T<=t) one-tail	0.36	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.71	
t Critical two-tail	2.16	

Scenario 3:

	w/o ASAP	*25min Reduction*
Mean	16372.88	16375.88
Variance	29903.84	22117.84
Observations	8.00	8.00
t Stat	-0.04	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.97	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	16372.88	16372.88
Variance	29903.84	24316.13
Observations	8.00	8.00
t Stat	0.00	
P(T<=t) one-tail	0.50	
t Critical one-tail	1.76	
P(T<=t) two-tail	1.00	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	16372.88	16314.63
Variance	29903.84	23276.55
Observations	8.00	8.00
t Stat	0.71	
P(T<=t) one-tail	0.24	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.49	
t Critical two-tail	2.14	

	w/o ASAP	*5 min Reduction*
Mean	16372.88	16375.25
Variance	29903.84	28107.64
Observations	8.00	8.00
t Stat	-0.03	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.98	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	16372.88	16365.88
Variance	29903.84	16717.27
Observations	8.00	8.00
t Stat	0.09	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.93	
t Critical two-tail	2.16	

Scenario 4:

	w/o ASAP	*25min Reduction*
Mean	14770.25	14753.75
Variance	4361.07	5748.79
Observations	8.00	8.00
t Stat	0.46	
P(T<=t) one-tail	0.32	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.65	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	14770.25	14766.88
Variance	4361.07	4193.55
Observations	8.00	8.00
t Stat	0.10	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.92	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	14770.25	14743.50
Variance	4361.07	5847.14
Observations	8.00	8.00
t Stat	0.75	
P(T<=t) one-tail	0.23	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.47	
t Critical two-tail	2.14	

	w/o ASAP	*5 min Reduction*
Mean	14770.25	14771.63
Variance	4361.07	3326.84
Observations	8.00	8.00
t Stat	-0.04	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.97	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	14770.25	14760.13
Variance	4361.07	5668.70
Observations	8.00	8.00
t Stat	0.29	
P(T<=t) one-tail	0.39	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.78	
t Critical two-tail	2.14	

Scenario 5:

	w/o ASAP	25min Reduction
Mean	25175.13	25125.13
Variance	9565.55	25246.41
Observations	8.00	8.00
t Stat	0.76	
P(T<=t) one-tail	0.23	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.46	
t Critical two-tail	2.18	

	w/o ASAP	10 min Reduction
Mean	25175.13	25164.00
Variance	9565.55	14468.29
Observations	8.00	8.00
t Stat	0.20	
P(T<=t) one-tail	0.42	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.84	
t Critical two-tail	2.16	

	w/o ASAP	20min Reduction
Mean	25175.13	25123.13
Variance	9565.55	15005.43
Observations	8.00	8.00
t Stat	-0.03	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.98	
t Critical two-tail	2.16	

	w/o ASAP	5 min Reduction
Mean	25175.13	25166.25
Variance	9565.55	12443.07
Observations	8.00	8.00
t Stat	0.17	
P(T<=t) one-tail	0.43	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.87	
t Critical two-tail	2.14	

	w/o ASAP	15 min Reduction
Mean	25175.13	25096.25
Variance	9565.55	17155.07
Observations	8.00	8.00
t Stat	1.36	
P(T<=t) one-tail	0.10	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.20	
t Critical two-tail	2.16	

Scenario 6:

	w/o ASAP	25min Reduction
Mean	10150.57	10162.25
Variance	830.29	797.36
Observations	8.00	8.00
t Stat	-0.79	
P(T<=t) one-tail	0.22	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.44	
t Critical two-tail	2.16	

	w/o ASAP	10 min Reduction
Mean	10150.57	10153.00
Variance	830.29	921.14
Observations	8.00	8.00
t Stat	-0.16	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.88	
t Critical two-tail	2.16	

	w/o ASAP	20min Reduction
Mean	10150.57	10152.25
Variance	830.29	965.07
Observations	8.00	8.00
t Stat	-0.11	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.92	
t Critical two-tail	2.16	

	w/o ASAP	5 min Reduction
Mean	10150.57	10147.75
Variance	830.29	641.07
Observations	8.00	8.00
t Stat	0.20	
P(T<=t) one-tail	0.42	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.84	
t Critical two-tail	2.18	

	w/o ASAP	15 min Reduction
Mean	10150.57	10159.88
Variance	830.29	1126.98
Observations	8.00	8.00
t Stat	-0.58	
P(T<=t) one-tail	0.29	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.57	
t Critical two-tail	2.16	

Scenario 7:

	w/o ASAP	*25min Reduction*
Mean	21447.13	21408.38
Variance	14391.84	24777.13
Observations	8.00	8.00
t Stat	0.55	
P(T<=t) one-tail	0.29	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.59	
t Critical two-tail	2.16	

	w/o ASAP	*10 min Reduction*
Mean	21447.13	21426.00
Variance	14391.84	15983.14
Observations	8.00	8.00
t Stat	0.34	
P(T<=t) one-tail	0.37	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.74	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	21447.13	21378.75
Variance	14391.84	22789.36
Observations	8.00	8.00
t Stat	1.00	
P(T<=t) one-tail	0.17	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.33	
t Critical two-tail	2.16	

	w/o ASAP	*5 min Reduction*
Mean	21447.13	21420.14
Variance	14391.84	17531.81
Observations	8.00	7.00
t Stat	0.41	
P(T<=t) one-tail	0.34	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.69	
t Critical two-tail	2.18	

	w/o ASAP	*15 min Reduction*
Mean	21447.13	21414.29
Variance	14391.84	7459.24
Observations	8.00	7.00
t Stat	0.61	
P(T<=t) one-tail	0.28	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.55	
t Critical two-tail	2.16	

Scenario 8:

	w/o ASAP	*25min Reduction*
Mean	16380.00	16410.63
Variance	8340.00	3090.84
Observations	8.00	8.00
t Stat	-0.81	
P(T<=t) one-tail	0.22	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.43	
t Critical two-tail	2.18	

	w/o ASAP	*10 min Reduction*
Mean	16380.00	16382.88
Variance	8340.00	8321.55
Observations	8.00	8.00
t Stat	-0.06	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.95	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	16380.00	16380.75
Variance	8340.00	7700.50
Observations	8.00	8.00
t Stat	-0.02	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.99	
t Critical two-tail	2.14	

	w/o ASAP	*5 min Reduction*
Mean	16380.00	16377.00
Variance	8340.00	8737.14
Observations	8.00	8.00
t Stat	0.06	
P(T<=t) one-tail	0.47	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.95	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	16380.00	16381.63
Variance	8340.00	5607.13
Observations	8.00	8.00
t Stat	-0.04	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.97	
t Critical two-tail	2.16	

Scenario 9:

	w/o ASAP	25min Reduction
Mean	5909.00	5911.13
Variance	552.00	679.84
Observations	8.00	8.00
t Stat	-0.17	
P(T<=t) one-tail	0.43	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.87	
t Critical two-tail	2.14	

	w/o ASAP	10 min Reduction
Mean	5909.00	5915.63
Variance	552.00	977.13
Observations	8.00	8.00
t Stat	-0.48	
P(T<=t) one-tail	0.32	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.64	
t Critical two-tail	2.16	

	w/o ASAP	20min Reduction
Mean	5909.00	5911.38
Variance	552.00	308.27
Observations	8.00	8.00
t Stat	-0.23	
P(T<=t) one-tail	0.41	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.82	
t Critical two-tail	2.16	

	w/o ASAP	5 min Reduction
Mean	5909.00	5910.13
Variance	552.00	583.55
Observations	8.00	8.00
t Stat	-0.09	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.93	
t Critical two-tail	2.14	

	w/o ASAP	15 min Reduction
Mean	5909.00	5911.00
Variance	552.00	532.86
Observations	8.00	8.00
t Stat	-0.17	
P(T<=t) one-tail	0.43	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.87	
t Critical two-tail	2.14	

Scenario 10:

	w/o ASAP	25min Reduction
Mean	11065.25	11064.13
Variance	2415.36	998.13
Observations	8.00	8.00
t Stat	0.05	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.96	
t Critical two-tail	2.18	

	w/o ASAP	10 min Reduction
Mean	11065.25	11069.00
Variance	2415.36	2001.71
Observations	8.00	8.00
t Stat	-0.16	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.88	
t Critical two-tail	2.14	

	w/o ASAP	20min Reduction
Mean	11065.25	11062.13
Variance	2415.36	2012.98
Observations	8.00	8.00
t Stat	0.13	
P(T<=t) one-tail	0.45	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.90	
t Critical two-tail	2.14	

	w/o ASAP	5 min Reduction
Mean	11065.25	11068.75
Variance	2415.36	1775.07
Observations	8.00	8.00
t Stat	-0.15	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.88	
t Critical two-tail	2.14	

	w/o ASAP	15 min Reduction
Mean	11065.25	11066.00
Variance	2415.36	1345.14
Observations	8.00	8.00
t Stat	-0.03	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.97	
t Critical two-tail	2.16	

Scenario 11:

	w/o ASAP	*25min Reduction*
Mean	10157.38	10157.00
Variance	1383.13	1094.57
Observations	8.00	8.00
t Stat	0.02	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.98	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	10157.38	10163.88
Variance	1383.13	797.27
Observations	8.00	8.00
t Stat	-0.39	
P(T<=t) one-tail	0.35	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.70	
t Critical two-tail	2.16	

	w/o ASAP	*20min Reduction*
Mean	10157.38	10156.38
Variance	1383.13	1134.84
Observations	8.00	8.00
t Stat	0.06	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.96	
t Critical two-tail	2.14	

	w/o ASAP	*5 min Reduction*
Mean	10157.38	10158.13
Variance	1383.13	1102.70
Observations	8.00	8.00
t Stat	-0.04	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.97	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	10157.38	10150.75
Variance	1383.13	1051.07
Observations	8.00	8.00
t Stat	0.38	
P(T<=t) one-tail	0.35	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.71	
t Critical two-tail	2.14	

Scenario 12:

	w/o ASAP	25min Reduction
Mean	10573.00	10567.75
Variance	151.71	841.07
Observations	8.00	8.00
t Stat	0.47	
P(T<=t) one-tail	0.32	
t Critical one-tail	1.83	
P(T<=t) two-tail	0.65	
t Critical two-tail	2.26	

	w/o ASAP	10 min Reduction
Mean	10573.00	10572.38
Variance	151.71	519.70
Observations	8.00	8.00
t Stat	0.07	
P(T<=t) one-tail	0.47	
t Critical one-tail	1.80	
P(T<=t) two-tail	0.95	
t Critical two-tail	2.20	

	w/o ASAP	20min Reduction
Mean	10573.00	10577.13
Variance	151.71	390.13
Observations	8.00	8.00
t Stat	-0.50	
P(T<=t) one-tail	0.31	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.63	
t Critical two-tail	2.18	

	w/o ASAP	5 min Reduction
Mean	10573.00	10575.75
Variance	151.71	371.64
Observations	8.00	8.00
t Stat	-0.34	
P(T<=t) one-tail	0.37	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.74	
t Critical two-tail	2.18	

	w/o ASAP	15 min Reduction
Mean	10573.00	10583.75
Variance	151.71	219.07
Observations	8.00	8.00
t Stat	-1.58	
P(T<=t) one-tail	0.07	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.14	
t Critical two-tail	2.14	

Scenario 13:

	w/o ASAP	25min Reduction
Mean	16636.50	16182.75
Variance	16781.71	17054.21
Observations	8.00	8.00
t Stat	6.98	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.14	

	w/o ASAP	10 min Reduction
Mean	16636.50	16504.00
Variance	16781.71	17549.71
Observations	8.00	8.00
t Stat	2.02	
P(T<=t) one-tail	0.03	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.06	
t Critical two-tail	2.14	

	w/o ASAP	20min Reduction
Mean	16636.50	16249.88
Variance	16781.71	19818.70
Observations	8.00	8.00
t Stat	5.72	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.14	

	w/o ASAP	5 min Reduction
Mean	16636.50	16559.38
Variance	16781.71	16257.98
Observations	8.00	8.00
t Stat	1.20	
P(T<=t) one-tail	0.13	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.25	
t Critical two-tail	2.14	

	w/o ASAP	15 min Reduction
Mean	16636.50	16390.50
Variance	16781.71	22451.14
Observations	8.00	8.00
t Stat	3.51	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.14	

Scenario 14:

	w/o ASAP	*25min Reduction*
Mean	11641.57	11658.00
Variance	2500.29	2883.43
Observations	8.00	8.00
t Stat	-0.61	
P(T<=t) one-tail	0.28	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.55	
t Critical two-tail	2.16	

	w/o ASAP	*10 min Reduction*
Mean	11641.57	11641.25
Variance	2500.29	2354.21
Observations	8.00	8.00
t Stat	0.01	
P(T<=t) one-tail	0.50	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.99	
t Critical two-tail	2.16	

	w/o ASAP	*20min Reduction*
Mean	11641.57	11645.63
Variance	2500.29	3343.70
Observations	8.00	8.00
t Stat	-0.15	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.89	
t Critical two-tail	2.16	

	w/o ASAP	*5 min Reduction*
Mean	11641.57	11637.38
Variance	2500.29	1984.84
Observations	8.00	8.00
t Stat	0.17	
P(T<=t) one-tail	0.43	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.87	
t Critical two-tail	2.18	

	w/o ASAP	*15 min Reduction*
Mean	11641.57	11643.88
Variance	2500.29	2628.98
Observations	8.00	8.00
t Stat	-0.09	
P(T<=t) one-tail	0.47	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.93	
t Critical two-tail	2.16	

Scenario 15:

	w/o ASAP	*25min Reduction*
Mean	11671.13	11656.13
Variance	3267.27	2967.27
Observations	8.00	8.00
t Stat	0.54	
P(T<=t) one-tail	0.30	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.60	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	11671.13	11669.13
Variance	3267.27	3107.84
Observations	8.00	8.00
t Stat	0.07	
P(T<=t) one-tail	0.47	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.94	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	11671.13	11659.57
Variance	3267.27	3564.95
Observations	8.00	7.00
t Stat	0.38	
P(T<=t) one-tail	0.35	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.71	
t Critical two-tail	2.16	

	w/o ASAP	*5 min Reduction*
Mean	11671.13	11669.38
Variance	3267.27	3837.98
Observations	8.00	8.00
t Stat	0.06	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.95	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	11671.13	11672.25
Variance	3267.27	2600.79
Observations	8.00	8.00
t Stat	-0.04	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.97	
t Critical two-tail	2.14	

Scenario 16:

	w/o ASAP	25min Reduction
Mean	8268.25	8268.63
Variance	1218.21	1303.41
Observations	8.00	8.00
t Stat	-0.02	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.98	
t Critical two-tail	2.14	

	w/o ASAP	10 min Reduction
Mean	8268.25	8266.38
Variance	1218.21	971.41
Observations	8.00	8.00
t Stat	0.11	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.91	
t Critical two-tail	2.14	

	w/o ASAP	20min Reduction
Mean	8268.25	8273.88
Variance	1218.21	188.41
Observations	8.00	8.00
t Stat	-0.42	
P(T<=t) one-tail	0.34	
t Critical one-tail	1.83	
P(T<=t) two-tail	0.68	
t Critical two-tail	2.26	

	w/o ASAP	5 min Reduction
Mean	8268.25	8268.38
Variance	1218.21	1247.13
Observations	8.00	8.00
t Stat	-0.01	
P(T<=t) one-tail	0.50	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.99	
t Critical two-tail	2.14	

	w/o ASAP	15 min Reduction
Mean	8268.25	8273.57
Variance	1218.21	815.62
Observations	8.00	7.00
t Stat	-0.32	
P(T<=t) one-tail	0.38	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.75	
t Critical two-tail	2.16	

Scenario 17:

	w/o ASAP	*25min Reduction*
Mean	5918.38	5909.00
Variance	777.13	670.29
Observations	8.00	8.00
t Stat	0.70	
P(T<=t) one-tail	0.25	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.50	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	5918.38	5914.63
Variance	777.13	566.55
Observations	8.00	8.00
t Stat	0.29	
P(T<=t) one-tail	0.39	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.78	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	5918.38	5908.63
Variance	777.13	396.27
Observations	8.00	8.00
t Stat	0.81	
P(T<=t) one-tail	0.22	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.44	
t Critical two-tail	2.16	

	w/o ASAP	*5 min Reduction*
Mean	5918.38	5915.75
Variance	777.13	525.07
Observations	8.00	8.00
t Stat	0.21	
P(T<=t) one-tail	0.42	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.84	
t Critical two-tail	2.16	

	w/o ASAP	*15 min Reduction*
Mean	5918.38	5916.57
Variance	777.13	978.29
Observations	8.00	7.00
t Stat	0.12	
P(T<=t) one-tail	0.45	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.91	
t Critical two-tail	2.18	

Scenario 18:

	w/o ASAP	*25min Reduction*
Mean	12456.63	12464.88
Variance	2499.41	2343.27
Observations	8.00	8.00
t Stat	-0.34	
P(T<=t) one-tail	0.37	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.74	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	12456.63	12464.00
Variance	2499.41	2952.29
Observations	8.00	8.00
t Stat	-0.28	
P(T<=t) one-tail	0.39	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.78	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	12456.63	12468.38
Variance	2499.41	2236.27
Observations	8.00	8.00
t Stat	-0.48	
P(T<=t) one-tail	0.32	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.64	
t Critical two-tail	2.14	

	w/o ASAP	*5 min Reduction*
Mean	12456.63	12459.38
Variance	2499.41	2571.41
Observations	8.00	8.00
t Stat	-0.11	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.91	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	12456.63	12464.00
Variance	2499.41	1082.86
Observations	8.00	8.00
t Stat	-0.35	
P(T<=t) one-tail	0.37	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.73	
t Critical two-tail	2.18	

Scenario 19:

	w/o ASAP	*25min Reduction*
Mean	11654.71	11646.57
Variance	5007.24	3500.29
Observations	8.00	8.00
t Stat	0.23	
P(T<=t) one-tail	0.41	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.82	
t Critical two-tail	2.18	

	w/o ASAP	*10 min Reduction*
Mean	11654.71	11649.43
Variance	5007.24	4610.95
Observations	8.00	8.00
t Stat	0.14	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.89	
t Critical two-tail	2.18	

	w/o ASAP	*20min Reduction*
Mean	11654.71	11656.57
Variance	5007.24	6193.62
Observations	8.00	8.00
t Stat	-0.05	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.96	
t Critical two-tail	2.18	

	w/o ASAP	*5 min Reduction*
Mean	11654.71	11652.29
Variance	5007.24	4628.90
Observations	8.00	8.00
t Stat	0.07	
P(T<=t) one-tail	0.47	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.95	
t Critical two-tail	2.18	

	w/o ASAP	*15 min Reduction*
Mean	11654.71	11637.29
Variance	5007.24	4171.90
Observations	8.00	8.00
t Stat	0.48	
P(T<=t) one-tail	0.32	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.64	
t Critical two-tail	2.18	

Scenario 20:

	w/o ASAP	*25min Reduction*
Mean	6876.63	6889.13
Variance	396.27	473.27
Observations	8.00	8.00
t Stat	-1.20	
P(T<=t) one-tail	0.13	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.25	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	6876.63	6879.50
Variance	396.27	245.14
Observations	8.00	8.00
t Stat	-0.32	
P(T<=t) one-tail	0.38	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.75	
t Critical two-tail	2.16	

	w/o ASAP	*20min Reduction*
Mean	6876.63	6890.75
Variance	396.27	870.50
Observations	8.00	8.00
t Stat	-1.12	
P(T<=t) one-tail	0.14	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.28	
t Critical two-tail	2.18	

	w/o ASAP	*5 min Reduction*
Mean	6876.63	6875.75
Variance	396.27	233.36
Observations	8.00	8.00
t Stat	0.10	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.92	
t Critical two-tail	2.16	

	w/o ASAP	*15 min Reduction*
Mean	6876.63	6895.88
Variance	396.27	1422.41
Observations	8.00	8.00
t Stat	-1.28	
P(T<=t) one-tail	0.11	
t Critical one-tail	1.80	
P(T<=t) two-tail	0.23	
t Critical two-tail	2.20	

Scenario 21:

	w/o ASAP	25min Reduction
Mean	14237.50	14224.13
Variance	3875.14	4335.55
Observations	8.00	8.00
t Stat	0.42	
P(T<=t) one-tail	0.34	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.68	
t Critical two-tail	2.14	

	w/o ASAP	10 min Reduction
Mean	14237.50	14230.50
Variance	3875.14	5500.57
Observations	8.00	8.00
t Stat	0.20	
P(T<=t) one-tail	0.42	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.84	
t Critical two-tail	2.14	

	w/o ASAP	20min Reduction
Mean	14237.50	14211.75
Variance	3875.14	3166.79
Observations	8.00	8.00
t Stat	0.87	
P(T<=t) one-tail	0.20	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.40	
t Critical two-tail	2.14	

	w/o ASAP	5 min Reduction
Mean	14237.50	14238.88
Variance	3875.14	4896.41
Observations	8.00	8.00
t Stat	-0.04	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.97	
t Critical two-tail	2.14	

	w/o ASAP	15 min Reduction
Mean	14237.50	14217.88
Variance	3875.14	6150.41
Observations	8.00	8.00
t Stat	0.55	
P(T<=t) one-tail	0.29	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.59	
t Critical two-tail	2.16	

Scenario 22:

	w/o ASAP	*25min Reduction*
Mean	16720.38	16736.00
Variance	16887.70	19790.86
Observations	8.00	8.00
t Stat	-0.23	
P(T<=t) one-tail	0.41	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.82	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	16720.38	16721.50
Variance	16887.70	13120.86
Observations	8.00	8.00
t Stat	-0.02	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.99	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	16720.38	16721.00
Variance	16887.70	15115.33
Observations	8.00	7.00
t Stat	-0.01	
P(T<=t) one-tail	0.50	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.99	
t Critical two-tail	2.16	

	w/o ASAP	*5 min Reduction*
Mean	16720.38	16724.00
Variance	16887.70	13428.57
Observations	8.00	8.00
t Stat	-0.06	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.95	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	16720.38	16727.13
Variance	16887.70	21499.84
Observations	8.00	8.00
t Stat	-0.10	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.92	
t Critical two-tail	2.14	

Scenario 23:

	w/o ASAP	25min Reduction
Mean	21429.75	21329.13
Variance	26585.36	26244.41
Observations	8.00	8.00
t Stat	1.24	
P(T<=t) one-tail	0.12	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.24	
t Critical two-tail	2.14	

	w/o ASAP	10 min Reduction
Mean	21429.75	21381.29
Variance	26585.36	32652.90
Observations	8.00	7.00
t Stat	0.54	
P(T<=t) one-tail	0.30	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.60	
t Critical two-tail	2.18	

	w/o ASAP	20min Reduction
Mean	21429.75	21404.63
Variance	26585.36	21365.98
Observations	8.00	8.00
t Stat	0.32	
P(T<=t) one-tail	0.38	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.75	
t Critical two-tail	2.14	

	w/o ASAP	5 min Reduction
Mean	21429.75	21411.75
Variance	26585.36	21889.93
Observations	8.00	8.00
t Stat	0.23	
P(T<=t) one-tail	0.41	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.82	
t Critical two-tail	2.14	

	w/o ASAP	15 min Reduction
Mean	21429.75	21361.88
Variance	26585.36	18383.84
Observations	8.00	8.00
t Stat	0.91	
P(T<=t) one-tail	0.19	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.38	
t Critical two-tail	2.14	

Scenario 24:

	w/o ASAP	*25min Reduction*
Mean	10517.75	10366.38
Variance	3141.64	1276.84
Observations	8.00	8.00
t Stat	6.44	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.18	

	w/o ASAP	*10 min Reduction*
Mean	10517.75	10443.13
Variance	3141.64	1171.84
Observations	8.00	8.00
t Stat	3.21	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.01	
t Critical two-tail	2.18	

	w/o ASAP	*20min Reduction*
Mean	10517.75	10400.25
Variance	3141.64	1333.93
Observations	8.00	8.00
t Stat	4.97	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.18	

	w/o ASAP	*5 min Reduction*
Mean	10517.75	10477.88
Variance	3141.64	894.13
Observations	8.00	8.00
t Stat	1.78	
P(T<=t) one-tail	0.05	
t Critical one-tail	1.80	
P(T<=t) two-tail	0.10	
t Critical two-tail	2.20	

	w/o ASAP	*15 min Reduction*
Mean	10517.75	10432.63
Variance	3141.64	1325.41
Observations	8.00	8.00
t Stat	3.60	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.00	
t Critical two-tail	2.18	

Scenario 25:

	w/o ASAP	*25min Reduction*
Mean	6888.00	6890.25
Variance	430.57	788.50
Observations	8.00	8.00
t Stat	-0.18	
P(T<=t) one-tail	0.43	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.86	
t Critical two-tail	2.16	

	w/o ASAP	*10 min Reduction*
Mean	6888.00	6890.57
Variance	430.57	383.62
Observations	8.00	7.00
t Stat	-0.25	
P(T<=t) one-tail	0.40	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.81	
t Critical two-tail	2.16	

	w/o ASAP	*20min Reduction*
Mean	6888.00	6885.13
Variance	430.57	634.70
Observations	8.00	8.00
t Stat	0.25	
P(T<=t) one-tail	0.40	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.81	
t Critical two-tail	2.14	

	w/o ASAP	*5 min Reduction*
Mean	6888.00	6891.75
Variance	430.57	322.79
Observations	8.00	8.00
t Stat	-0.39	
P(T<=t) one-tail	0.35	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.70	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	6888.00	6884.13
Variance	430.57	109.55
Observations	8.00	8.00
t Stat	0.47	
P(T<=t) one-tail	0.32	
t Critical one-tail	1.81	
P(T<=t) two-tail	0.65	
t Critical two-tail	2.23	

Scenario 26:

	w/o ASAP	*25min Reduction*
Mean	12459.38	12460.25
Variance	2189.13	1612.50
Observations	8.00	8.00
t Stat	-0.04	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.97	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	12459.38	12462.63
Variance	2189.13	1327.13
Observations	8.00	8.00
t Stat	-0.16	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.88	
t Critical two-tail	2.16	

	w/o ASAP	*20min Reduction*
Mean	12459.38	12461.00
Variance	2189.13	2722.86
Observations	8.00	8.00
t Stat	-0.07	
P(T<=t) one-tail	0.47	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.95	
t Critical two-tail	2.14	

	w/o ASAP	*5 min Reduction*
Mean	12459.38	12454.38
Variance	2189.13	1621.98
Observations	8.00	8.00
t Stat	0.23	
P(T<=t) one-tail	0.41	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.82	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	12459.38	12453.25
Variance	2189.13	2875.93
Observations	8.00	8.00
t Stat	0.24	
P(T<=t) one-tail	0.41	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.81	
t Critical two-tail	2.14	

Scenario 27:

	w/o ASAP	25min Reduction
Mean	12490.88	12487.88
Variance	2335.55	1046.41
Observations	8.00	8.00
t Stat	0.15	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.89	
t Critical two-tail	2.18	

	w/o ASAP	10 min Reduction
Mean	12490.88	12493.88
Variance	2335.55	1920.13
Observations	8.00	8.00
t Stat	-0.13	
P(T<=t) one-tail	0.45	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.90	
t Critical two-tail	2.14	

	w/o ASAP	20min Reduction
Mean	12490.88	12486.75
Variance	2335.55	2557.36
Observations	8.00	8.00
t Stat	0.17	
P(T<=t) one-tail	0.43	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.87	
t Critical two-tail	2.14	

	w/o ASAP	5 min Reduction
Mean	12490.88	12494.38
Variance	2335.55	2264.84
Observations	8.00	8.00
t Stat	-0.15	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.89	
t Critical two-tail	2.14	

	w/o ASAP	15 min Reduction
Mean	12490.88	12493.63
Variance	2335.55	3894.84
Observations	8.00	8.00
t Stat	-0.10	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.92	
t Critical two-tail	2.16	

Scenario 28:

	w/o ASAP	*25min Reduction*
Mean	10582.13	10582.38
Variance	744.13	637.70
Observations	8.00	8.00
t Stat	-0.02	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.99	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	10582.13	10577.25
Variance	744.13	1031.93
Observations	8.00	8.00
t Stat	0.33	
P(T<=t) one-tail	0.37	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.75	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	10582.13	10587.50
Variance	744.13	713.43
Observations	8.00	8.00
t Stat	-0.40	
P(T<=t) one-tail	0.35	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.70	
t Critical two-tail	2.14	

	w/o ASAP	*5 min Reduction*
Mean	10582.13	10580.25
Variance	744.13	891.36
Observations	8.00	8.00
t Stat	0.13	
P(T<=t) one-tail	0.45	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.90	
t Critical two-tail	2.14	

	w/o ASAP	*15 min Reduction*
Mean	10582.13	10581.75
Variance	744.13	777.07
Observations	8.00	8.00
t Stat	0.03	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.98	
t Critical two-tail	2.14	

Scenario 29:

	w/o ASAP	*25min Reduction*
Mean	18941.38	18940.00
Variance	13574.55	15317.43
Observations	8.00	8.00
t Stat	0.02	
P(T<=t) one-tail	0.49	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.98	
t Critical two-tail	2.14	

	w/o ASAP	*10 min Reduction*
Mean	18941.38	18937.13
Variance	13574.55	16627.27
Observations	8.00	8.00
t Stat	0.07	
P(T<=t) one-tail	0.47	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.95	
t Critical two-tail	2.14	

	w/o ASAP	*20min Reduction*
Mean	18941.38	18940.88
Variance	13574.55	16545.27
Observations	8.00	8.00
t Stat	0.01	
P(T<=t) one-tail	0.50	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.99	
t Critical two-tail	2.14	

	w/o ASAP	*5 min Reduction*
Mean	18941.38	18952.14
Variance	13574.55	12619.81
Observations	8.00	7.00
t Stat	-0.18	
P(T<=t) one-tail	0.43	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.86	
t Critical two-tail	2.16	

	w/o ASAP	*15 min Reduction*
Mean	18941.38	18958.38
Variance	13574.55	17317.70
Observations	8.00	8.00
t Stat	-0.27	
P(T<=t) one-tail	0.39	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.79	
t Critical two-tail	2.14	

Scenario 30:

	w/o ASAP	25min Reduction
Mean	18983.38	18958.63
Variance	10245.41	16238.27
Observations	8.00	8.00
t Stat	0.43	
P(T<=t) one-tail	0.34	
t Critical one-tail	1.77	
P(T<=t) two-tail	0.67	
t Critical two-tail	2.16	

	w/o ASAP	10 min Reduction
Mean	18983.38	18988.25
Variance	10245.41	10718.79
Observations	8.00	8.00
t Stat	-0.10	
P(T<=t) one-tail	0.46	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.93	
t Critical two-tail	2.14	

	w/o ASAP	20min Reduction
Mean	18983.38	18997.71
Variance	10245.41	14279.24
Observations	8.00	8.00
t Stat	-0.25	
P(T<=t) one-tail	0.40	
t Critical one-tail	1.78	
P(T<=t) two-tail	0.81	
t Critical two-tail	2.18	

	w/o ASAP	5 min Reduction
Mean	18983.38	18991.00
Variance	10245.41	8507.71
Observations	8.00	8.00
t Stat	-0.16	
P(T<=t) one-tail	0.44	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.88	
t Critical two-tail	2.14	

	w/o ASAP	15 min Reduction
Mean	18983.38	18998.63
Variance	10245.41	9388.27
Observations	8.00	8.00
t Stat	-0.31	
P(T<=t) one-tail	0.38	
t Critical one-tail	1.76	
P(T<=t) two-tail	0.76	
t Critical two-tail	2.14	