The Ali-Scout Route Guidance Simulation

FAST-TRAC
Phase IIB Deliverable

#4 Report on Ali-Sout Simulation Runs at Various Levels of Market Penetration

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1. Introduction

Ah-Scout is a dynamic route guidance system with an In-Vehicle Unit (IVU) that receives routing information from a Traffic Operations Center when passing infixed communication beacons installed at strategic intersections.

As part of the FAST-TRAC evaluation, The University of Michigan Transportation Planning and Evaluation Group (UM TPEG) simulated traffic in order to assess the impacts of Ah-Scout as the system scales up to higher levels of market penetration. Ultimately, the UM will apply traffic simulation to determine the combined impacts of Ali-Scout and SCATS (Sydney Coordinated and Adaptive Traffic System) on traffic in the Oakland County deployment area.

In this document, we present and discuss the results of the evaluation of Ah-Scout using traffic modeling and simulation under a variety of scenarios. Section 2 describes the functional elements of the Ah-Scout system. Section 3 gives an overview of the simulation model. Section 4 includes a description of the simulation scope and the main simulation modules developed to represent the Ali-Scout router and guidance components. Section 5 describes the background traffic model used in simulation. In Section 6, we present and discuss the results of the Ah-Scout simulation runs. Section 7 concludes the report by summarizing the major results and providing insights as to the potential benefits of such a route guidance system

The simulation findings illustrate the effect of the level of market penetration on the individual and system performance. It appears that the benefits of Ah-Scout are signiticant only when the level of market penetration is below a certain level. Moreover, results show that the use of historical and real-time information as well as the density of beacon coverage play a major role in the effectiveness of this system.

2. Ali-Scout Operations

2.1 Ali-Scout Infrastructure and Network

The infrastructure of the Ali-Scout route guidance system consists of a Traffic Operations Center (TOC) with a complete set of global information (including roadway network and travel times databases) and a number of roadside substations, called beacons. One of the functions of the TOC is to compute Route Guidance Information (RGI) for traveling from each beacon location towards various destination zones, based on current traffic conditions and historical travel times. The TOC also transmits individual guidance information to each beacon.

Since many vehicles pass one beacon at the same time, it is not possible to transmit all the information by dialog between beacons and vehicles. Instead, a beacon transmits to all passing vehicles the total information for all possible destinations, as broadcast data. Each vehicle, knowing its own destination, extracts the appropriate RGI out of the complete data set. One major principle of Ali-Scout is that, for each destination, the TOC transmits to each beacon only the RGI that a passing vehicle will need until it reaches the next beacon. This reduces the amount of data received by the vehicle, and more importantly, it allows the vehicle to receive updated guidance information every time it passes a new beacon.

For purposes of data handling efficiency, the Ali-Scout deployed region, called *total region*, is subdivided by topological aspects into small contiguous *destination zones*. The minimal size of these zones is approximately 120 yard square. Each destination zone has one or more *departure points* around its boundary lines. These departure points are designated entry points to the destination zones. Figure 2-1 shows a hypothetical example of a traffic network subdivided into destination zones.

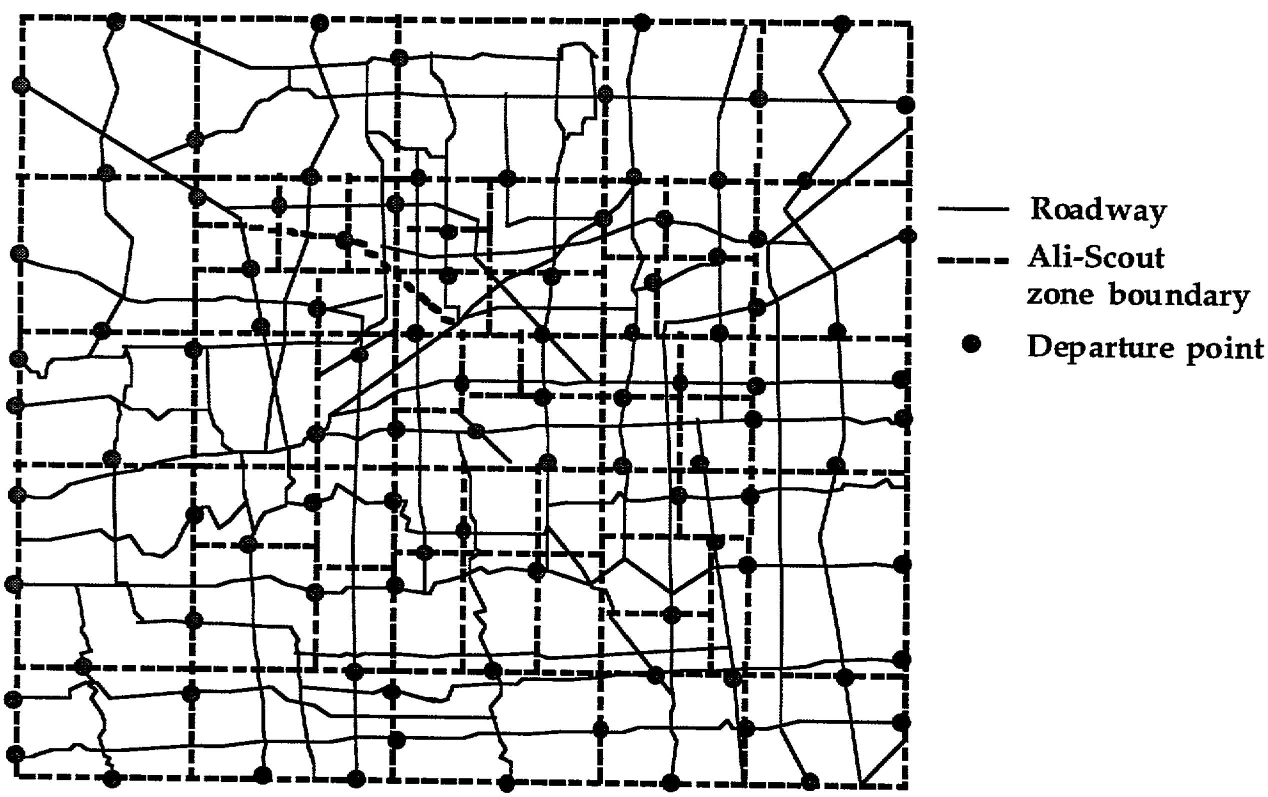

Figure 2-1: Example of Network with Ali-Scout Destination Zones

2.2 Destination Handling and Routing

The TOC periodically performs the route generation. It calculates the "best" routes based on specific criteria (typically the fastest), from each beacon exit to all destination zones among those that pass through a zone departure point. This route calculation is based on Loubal algorithm and an anticipatory (i.e., lookahead) travel time database with 8 time slices into the future (5minute duration per slice). Subsequently, the TOC computes, for each beacon, the so-called *beacon region* and the outer *region . The* beacon region is the region that includes all destination zones directly reached by *complete routes,* with passing at most one beacon [4]. The outer region contains all destination zones not included in the beacon region. By definition, a vehicle passing a beacon and having a destination in the outer region is guided *until the* next beacon *(incomplete route)* [4]. By definition, the outer regions are different for each exit of the current beacon, and therefore, they are computed for each exit by the TOC. After the outer region is defined, for a given beacon, all destination zones belonging to the outer region and having the same incomplete route are collapsed into one area, referred to as the *destination area.*

Figure 2-2 presents an example of Ah-Scout network. The destination zones are delimited by dashed lines, whereas the boundaries of the destination areas are represented by solid lines. The figure shows three routes from the current beacon, B_1, to the destination zones Z_1, Z_2 and Z_3 respectively. B_2 is the first beacon encountered by all vehicles driving along these routes. Hence all three zones should belong to the same destination area. This aggregation scheme is not an essential element in the routing function. Its only purpose is to reduce the amount of information (by eliminating redundancy) transmitted to the beacons, and subsequently to vehicles. It is important, however, to represent it in the simulation model since it provides an efficient data storage. It reduces the size of the routing tables which can be numerous under dynamic route guidance.

When the route computation (coded as *vectors)* is completed, the TOC transmits to each beacon the complete routes to the destination zones of the bea-

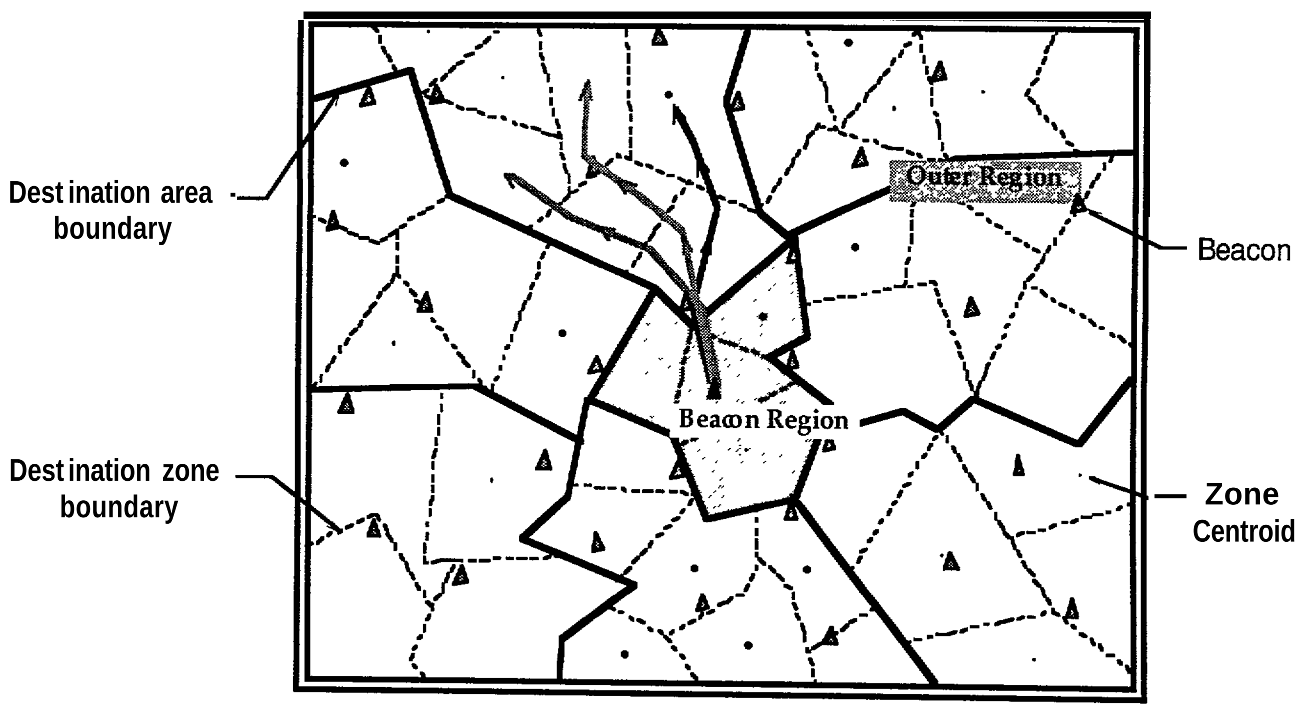

Figure 2-2: Example of AK-Scout Network

con region as well as the incomplete routes to the destination areas of the outer region. Once all beacons are downloaded, they begin using the live data simultaneously (i.e., transmitting RGI to passing vehicles). The RGI is periodically updated and downloaded to the beacons, with a cycle time of 5 minutes. This update is performed based on real-time link travel times transmitted from probe vehicles to beacons, then from beacons to the TOC. Typically, the beacons transmit such data to the TOC every minute. Transfers are done more frequently if the beacon memory fills up with vehicle telegrams. The operations of route calculation, zone aggregation, and data transfer between the TOC, beacons and vehicles am illustrated in Figure 4- 1.

The route computation is based on travel times between each beacon and the primary intersection that is nearest the geographic center of each destination zone. However, the routes transmitted to the beacons are cut back to a zone departure point.

It is important to note that the RGI transmitted to the beacons could include routes that extend to two beacons away, which is possible only when the amount of data does not exceed 64 K. This is advantageous especially when the first beacon passed breaks down. In this case, the vehicle does not lose guidance.

To summarize a vehicle's typical experience with the Ah-Scout system, the following sequence of events is described. Starting from an origin point, a vehicle is given an as-the-crow-flies guidance (also called autonomous mode) towards its destination until it crosses a beacon routing. When it passes by a beacon, it receives RGI to the next beacon on the recommended route or to a departure point (if no beacon is on the recommended route) for all destination zones and destination areas.

The vehicle then extracts the RGI it needs out of the complete data set. This is performed as follows. The IVU calculates the destination coordinates with respect to the beacon coordinates, assigns the selected travel destination to a specific destination zone or destination area and selects the appropriate route. When a vehicle reaches a departure point, after passing the last beacon on the recommended route, it switches to the autonomous mode towards its destination point.

3. Overview of the Simulation Model

The University of Michigan is using a network simulation model to represent and analyze the Ali-Scout system. The main characteristics of this model is that it abstracts away much of the link and intersection detail, as well as the inter-vehicle dynamics on-links and at intersections, in favor of capturing the global network dynamics of traffic responding to changes in demand, interacting with an integrated freeway/traffic signal network.

This simulation model has the following capabilities, which are particularly important for evaluating a route guidance system such as Ah-Scout:

- Ability to define a range of simultaneous routing strategies for vehicles entering the network (e.g., Ah-Scout router and background router),
- periodic update of routing matrices,
- Traffic control and route guidance interaction,
- modeling peak period congestion effects,
- incident modeling (as temporary link speed reduction or lane blockage), and
- individual vehicle tracking.

The model uses impedance functions and queues to move vehicles on the links. Due to the different characteristics of traffic flow that need to be modeled on freeways and at traffic signals, it analyzes traffic flow in terms of vehicles as individual entities. This approach permits a traffic flow representation common to both freeways and urban streets. Furthermore, it permits a continuous dynamic queuing-based traffic assignment. The common traffic flow representation is critical to modeling all network components in a consistent and compatible fashion, while the queuing-based dynamic traffic assignment technique is essential to dealing with diversion and re-routing of traffic during congestion and in response to any incidents.

The consideration of individual vehicles is primarily for purposes of improving the analysis resolution during the internal calculations, and does not necessarily require the user to collect or input data at the individual vehicle level. Instead, traffic flow characteristics and traffic demands can be specified by the user at an aggregate level (e.g., departure rates instead of exact specification of vehicles' departures), leaving it to the model routines to derive the measures related to individual vehicles.

The simulation emphasizes the time-dependent routing of individual vehicles through the Detroit Metro area. It assigns vehicles to routes connecting preassigned origin-destination pairs in accordance with a departure rate and a specified routing strategy. As time passes, vehicles enter the network at their origin, travel a specified path, and terminate the trip when the destination is reached. Vehicles enter-the network over time as specified by the departure rate distribution. The progress to the destination is influenced by a variety of factors including link capacities, congestion levels, traffic signals, and incidents. As in a real road network, a vehicle is slowed down by congestion that is caused by other vehicles on the network This congestion could take the form of link impedances and/or various forms of queueing.

There are several reasons for using a route-based network simulation for evaluating Ah-Scout. First, this type of simulation enables the evaluation of large numbers of vehicles using various routing strategies. In this case one of the routing strategies is an accurate representation of Ah-Scout. The performance of thousands of Ah-Scout vehicles can be compared with thousands of vehicles using other routing approaches. Small adjustments to parameters and other factors can be made at relatively little cost, and no risk to the vehicles or drivers. Second, the computational efficiency of the event-based program structure, and the simple queueing-based traffic representation, enables a sufficiently large network to be modeled for analysis of guidance and re-routing over realistic commute distances. Third, the simulation provides the mechanism for analyzing the interaction between traffic control and route guidance. The co-location of Ah-Scout and SCATS is planned for the next phase of the analysis.

4. Ali-Scout Simulation

4.1 Definitions of Simulation Components

Since the focus of the simulation is the Ali-Scout system, this section presents a detailed description of all the simulation modules and algorithms related to Ali-Scout. There are four main components of the simulator that can be deduced from the description of the Ali-Scout operations (as illustrated in figure 4-1).

Network Configuration: This can be viewed as the static database which contains the links and nodes description, the destination zone boundaries and beacon locations.

Travel Times Database: This database contains two types of data: (1) Real-time link travel times and, (2) time series of historical travel times. The first are generated and updated based on probe reports, link surveillance, and possibly other sources (e.g., SCATS database). The second provides expected future link travel times during various time periods.

Trip Data: One important component of the simulator, that is not an element of the Ali-Scout system per se, is the Origin-Destination (O-D) trip data that are used to load the network with vehicles driving from/to specific O-D zones.

Router and Destination Lookup: The router's major component is the fastest route algorithm that takes its input data from both the static and the dynamic databases and produces fastest routes between each beacon-destination zone pair. The destination lookup function is activated whenever a vehicle passes a beacon. The vehicle destination coordinates is matched with the appropriate destination area among those transferred from the beacon to the vehicle, and the appropriate RGI is selected.

The following four sections discuss and describe the above simulator components in detail.

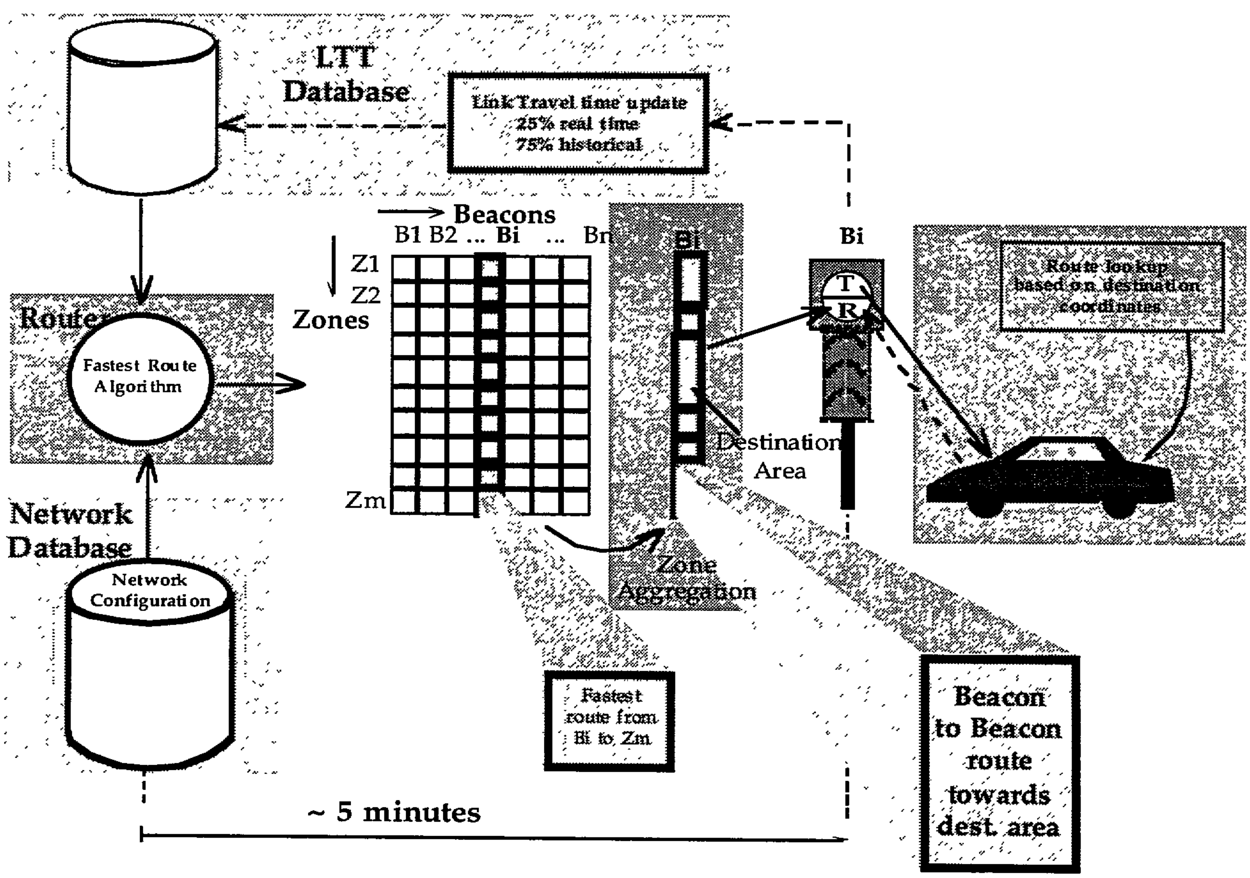

Figure 4 -1: Ali-Scout Route Guidance System

4.2 Network Configuration

The network currently used in the simulation spans three counties in southeastern Michigan: Oakland, Wayne and Macomb. This network is based on the Navigation Technologies database (NavTech, dated 4/1/95). The roadways defining the network, as shown on figure 4-2, were extracted form the NavTech database according to link classes. The following link classes, the first 6 out of the 17 provided by NavTech, are considered:

1. Highways with fully controlled and limited access
2. Highways with partially controlled access
3. Arterial streets or throughways
4. Few local, residential or rural roads
5. Few Frontage roads
6. Ramps

Figure 4-2: Roadway Network for Southeastern Michigan

4.3 Travel Time Database

The link travel times represent the attributes which are used to compute the paths, linking origins and destinations, on which guided and unguided vehicles are routed. Depending on the vehicle type and the type of guidance considered, static, real-time or historical travel times are selected as sources of data.

4.3.1 Real-Time Travel Times

These data represent the basic travel times available for each link of the network. If surveillance is available, then they reflect the link travel times actually experienced by vehicles traversing the network. If no surveillance is available, then these travel times are simply equal to the free-flow travel times.

The mode of surveillance considered in the simulation model represents vehicles that have the ability to transmit information to the TOC, through the beacons located at intersections. Specifically, this capability is restricted to probe vehicles (Ali-Scout equipped vehicles) which transmit their experienced travel times to roadside beacons upon exiting a link.

The real-time travel times are maintained by computing for each link, the exponentially smoothed average link travel time of all vehicles that are known to have traversed (i.e., probes). Each time a probe departs a link, the travel time for that link (and all previously traversed links, starting from the previously encountered beacon) is updated using Equation 4-1].

$$t^* = \alpha\, t_l + (1-\alpha)t \qquad [4\text{-}1]$$

where:

t^* = average link travel time incorporating the travel time experienced by the current vehicle (seconds)

α = smoothing factor (is currently used)

t_l = time required by current vehicle to traverse entire link (seconds)

t = previous average value of link travel time (seconds)

4.3.2 Historical Travel Times

This type of data consists of a time series of link travel times, which represent expected network conditions during various future time periods of the simulation. The duration of these time periods is 5 minutes, conforming to the specifications presented in Section 2-2. When an Ali-Scout equipped vehicle is routed based on this historical data, not only the expected link travel times at the time of its departure are considered, but also anticipated future travel conditions of the network (associated with future time periods) are taken into account. This is different from the real-time routing used in the simulation for some of the background (i.e., non-equipped) vehicles. For this background routing, future travel times beyond those specified for the time of departure are not utilized.

Since no historical LTT database is readily available to simulate Ah-Scout in the dynamic mode, a "simulated" historical database is constructed by running the simulation iteratively starting with the static mode. In this static mode, free flow speeds acquired from NavTech are used to derive link costs (i.e., travel times). Furthermore, this historical database is continuously updated as the level of market penetration increases. This is accomplished by updating the historical travel time database while running a market penetration scenario, then using the resulting database as input to the next market penetration scenario. For example, a 5% market penetration scenario is run using a historical database that is updated based on travel experiences of the Ah-Scout vehicles associated with the 1% market penetration scenario. The goal behind this procedure is to represent the continuous database update (i.e., standard profile) that is performed at the TOC.

4.4 Trip Data

Dynamic trip data occurring among the Ali-Scout zones are generated based on the 1995 static data provided by SEMCOG. These data represent only the trips generated the afternoon peak period (5:00 PM to 6:00 PM). Since we need to simulate traffic during the morning peak hours (6:00 AM **to** 10:00 AM), we use a simple procedure to extrapolate the morning O-D demand from the afternoon trip data. First, we **estimate the hourly trip distribution** for a typical day. Then, we use this distribution, combined **with the available afternoon trip data to** generate the nips for morning peak hours.

Hourly ***Trip Distribution:*** We use the K-factor[1] hourly distribution, provided by SEMCOG, as an estimate of the trip distribution (see figure 4-3). This distribution is consistent with the general travel observed by traffic engineers and used for the purpose of planning and designing new or improved highways [2].

Dynamic O-D Demand Estimation Given the daily profile and the number of trips occurring during the afternoon peak period the total number of trips generated during the morning peak period is estimated. This is assuming that the morning peak directions are the opposite of the afternoon peak directions. Furthermore, as the traffic demand within a peak period is not necessarily uniform, the entire peak period is broken down into a series of consecutive time slices (of 15 minutes), each time slice having its own separate O-D matrix. The resulting morning profile, depicted on 4-4, shows that traffic demand reaches its peak around 8:00 AM. The morning profile is then used to estimate the O-D demand for each 15-minute time slice.

The application of the above procedure resulted roughly in 750,000 vehicles spread spatially and temporally according to the morning peak hours distribution. It is important to note that the O-D matrix is based on SEMCOGos database and its own definition of origin/departure zones.

After observing the SEMCOG trip distribution on the roadway network, it appeared that the FAST-TRAC area (Oakland County) was not sufficiently covered for testing and evaluating the Ali-Scout capabilities. In fact, most of the trips cover Wayne County and particularly, the Detroit area. The majority of vehicles going through the FAST-TRAC area have short trips, which makes the use of any route guidance system very limited.

In order to get more realistic trip data for the Oakland County, we supplemented the SEMCOG data with trips generated based on land use information and the 1994 Michigan resident population estimates. A land use map of Southeastern Michigan

1. The K-factor is defined as **the highest percentage of trips in a single hour**

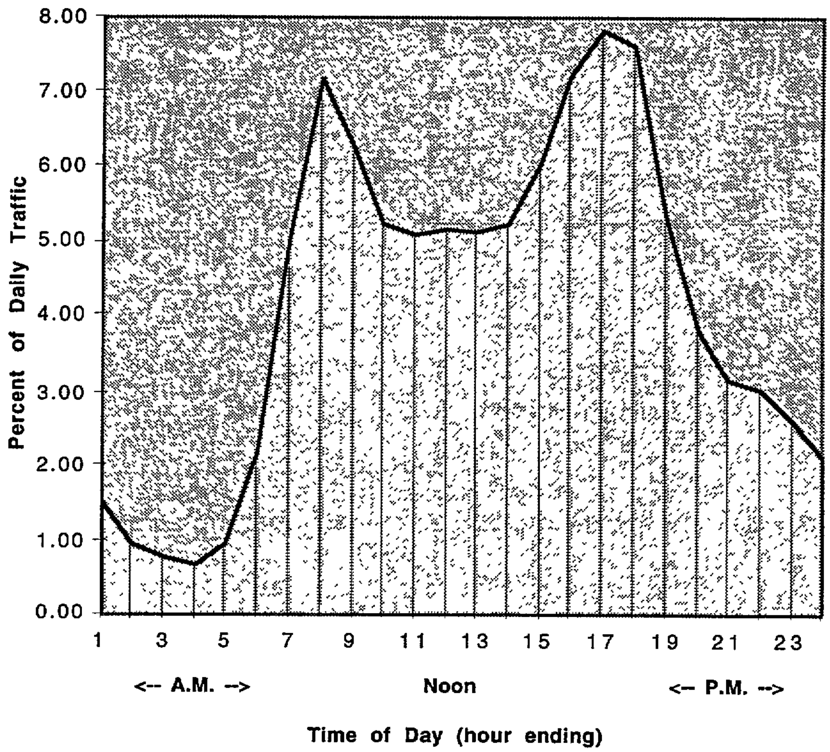

Figure 4-3: Hourly Distribution of Trips

was used to identify business areas (representing prospective destination zones) and residential areas (representing origins). The population estimate as well as statistics related to vehicle ownership and dwelling sizes (refer to [2] and [5] for more detail) were used to estimate the number of vehicles traveling between each O-D pair during the morning peak hours. This estimation procedure resulted in about **250,000** additional trips spread over the 4-hour simulation period. Therefore, the total number of trips

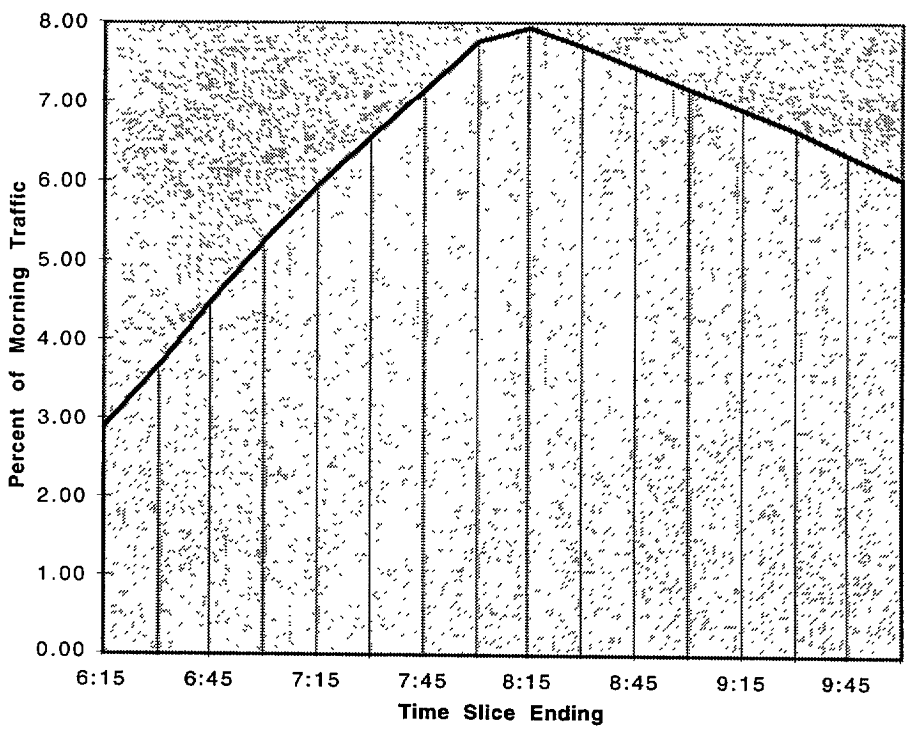

Figure 4-4: Morning Trip Distribution

generated is about **1,000,000**. However, since the total network capacity was already reduced by excluding many link classes, the total network load is also reduced to about 70%, which is equivalent to a total of **700,000** vehicles.

In addition, given that traffic is created by both background and Ali-Scout vehicles, the generated trips are split between these two vehicle classes according to the desired level of market penetration (i.e., percentage of Ali-Scout equipped vehicles).

4.5 Router

Two types of routing modes are implemented in the simulator. The first is the autonomous mode which is used by the vehicle at the beginning and at the end of its trip: first, between its origin and the next beacon encountered, and then between a zone departure point and the vehicle's final destination point. The second type is the beacon-to-beacon guidance mode which consists of providing the vehicle with a detailed link-to-link and turn-by-turn routing between two consecutive beacons on the pre-computed fastest route.

Autonomous Mode: Any vehicle entering the autonomous mode is routed towards its destination using a simple òdirectionaló routing. At the end of each link, the vehicle is moved to the next link that is the closest in directionality to the straight line joining its current position to its goal, regardless of whether or not that link lies on the fastest path.

Guidance Mode: Each time a vehicle enters a *node* (a term more general than *intersection* since a node may join two or more links) there are two possible outcomes: (1) If there is a beacon on the node, the vehicle receives a new path based on its destination, and hence moves to the next link on that new path. (2) If no beacon exists, then it continues moving along the shortest path previously assigned to it. In the second case, the vehicle moves on its current shortest path until it reaches a beacon. This guidance mode ends when the vehicle reaches a nodes that is identified as a departure point associated with its destination zone. The vehicle routing then switches to the autonomous mode.

As mentioned earlier, the Ali-Scout routes are computed based on Loubal algorithm. However, the details about this algorithm were not available to the University of Michigan simulation group. Therefore, an alternative lookahead shortest path algorithm was used in the simulation. It is based on the pioneering work of Dijkstra [1] and Moore [3], with the added lookeahead feature. The following is a description of the algorithm's pseudo-code that generates shortest paths from a given beacon (labeled as node 1) to all destination zone centroids (nodes that belong to the subset D, described below).

Notation

N number of nodes

$X = \{1,\ldots,N\}$ set of all nodes

D subset of X which contains destination nodes

Γ_i set of successors of node i

P index vector updated at step (3). When the algorithm terminates, $P(i)$ is the node index of the predecessor of i on the shortest path from 1 to i

$C_{ij}(t)$ cost of traveling from node i to node$i$, leaving node i at time t

S subset of X that contains node 1

$\bar{S} = X - S$

$v(i)$ a label of i which is the value of the shortest path from 1 to i if $i \in S$

Algorithm

(1) Initialization

$$\bar{S} = \{2, \ldots, N\}$$

$$, v(1) = 0, \quad v(i) = \begin{cases} c_{1i}(0) & \text{if } i \in \Gamma_1 \\ \infty & \text{Otherwise} \end{cases}$$

$$P(i) = 1, \ \forall i \in \Gamma_1$$

(2) Find $j \in \bar{S}$ such that $v(j) = \min_{i \in \bar{S}} v(i)$

Set $\bar{S} \leftarrow \bar{S} - \{j\}$, $S \leftarrow S \cup \{j\}$

If $|\bar{S}| = 0$, END; otherwise go to (3)

(3) For all $i \in \Gamma_j$ and $i \in \bar{S}$, set

$$v(i) \leftarrow \min\{v(i),\ v(j) + c_{ji}[v(j)]\} \quad [4\text{-}2]$$

$$P(i) = j, \text{ if } v(i) = v(j) + c_{ji}[v(j)]$$

go to (2)

The above algorithm actually finds one shortest path from the start node (beacon location) to each other node in the network. Since, we are interested only in nodes that represent destination zones, a better stopping criteria is when all nodes in the set D are visited (i.e., $|\bar{S} \cap D| = 0$ instead of $|\bar{S}| = 0$).

The lookahead feature is exhibited in Equation [4-2] where the travel time from node j to node i $c_{ji}[v(j)]$ is a function of the time at which a vehicle arrives at node j $v(j)$. The algorithm, however, may be used for calculating shortest paths without the lookahead feature by simply using constant link travel times. This would result in substituting c_{ji} for $c_{ji}[v(j)]$.

5. Modeling Background Traffic

Background (i.e., unguided) vehicles are generally driven by commuters familiar with the route during the peak period. Commuters minimize their trip time with relatively little navigational error. Typically, these drivers anticipate recurring traffic and make routing adjustments over time to minimize their overall travel time. In addition, background vehicles are slower to respond to incidents and to recurrent congestion than guided vehicles.

This simulation model uses a combination of route assignment methods to represent background traffic during the morning commute. The goal is to achieve a realistic temporal and spatial distribution of vehicles while representing different types of travel behavior. Typically, these drivers anticipate recurring traffic and make routing adjustments over time to minimize their overall travel time. In addition, background vehicles are slower to respond to incidents and to recurrent congestion than guided vehicles. Two routing strategies are implemented to represent the background traffic: anticipatory-based route assignment and real-time routing with path archiving.

Anticipatory-based route assignment: On a given day, drivers who are familiar with network conditions should be able to make efficient pre-trip route choices. Typically, these drivers are influenced by historical perceptions of travel time. Hence, they anticipate recurring traffic and make routing adjustments over time to minimize their overall trip time. In this model, routes assigned to drivers of this class are computed using a lookahead shortest path algorithm. This algorithm uses travel times that reflect current as well as anticipated traffic conditions, and is applied iteratively to more closely represent the way drivers adjust their perception and knowledge of traffic conditions over time. However, drivers of this class follow their initial routes until the end of their trips and are slow in responding to incidents.

Real-time routing with path archiving. This routing strategy represents the stochastic and complex nature of a group of drivers. This group may include unfamiliar drivers who stay on their initial path until they reach their destinations, and those who update their paths based on perceived current traffic conditions. Paths assigned to these drivers are shortest paths computed using travel times available at the time of computation. Periodically (every 20 minutes), a new set of paths is computed, and a random subset of drivers switches to these new paths. The remaining drivers stay on their current paths (referred to as “archived”). The link travel times are estimated based on the experience of all background vehicles. These estimates are generated using the exponential smoothing model defined by Equation 4-1, with a smoothing factor $a = 0.20$. This model achieves a realistic distribution of traffic and captures some of the dynamics of congested traffic behavior, at no added computational complexity.

Although two distinct classes of drivers are used to model the background traffic the following simulation analysis reports only on the overall measures of effectiveness (i.e., averaged over the drivers of both classes). These measures of effectiveness are referred to being related to ***unguided*** (or background) vehicles. An in-depth study of the behavior of these two classes is beyond the scope of this evaluation effort.

6. Simulation Resutts

6.1 Scenario Description

The objective of the simulation is to perform a quantitative evaluation of the operational impacts of the Ah-Scout system on traffic under various levels of market penetration. Six levels of market penetration are considered in the simulation: 0%, 1% 5%, 10% 15% and 20%.

The selection of the morning peak hours as the simulation period provides an excellent opportunity to simulate traffic under the condition of recurrent congestion. In addition to this naturally occurring congestion, incident cases are also considered. This provides an opportunity to measure the effectiveness of the Ah-Scout system under different network conditions, where a significant delay is caused for many travelers in the network

The incident case is designed based on data acquired from MDOT, related to incidents that have occurred during 1995 in the Detroit Metro Area. Three incidents are introduced. They are specified by their location, start time, end time, and the number of lanes affected. The latter represents the reduction in capacity of the link on which the incident takes place. Although these incidents do not necessarily occur at the same time, they are grouped under a single scenario (i.e., one simulation run is needed to capture their effect). Details about incident specifications are shown on.

Table 6-1: Incident Scenarios

Incident Identification Number	Location	Start Time	End Time	Effective Speed *
1	I-75 NB at Rochester	7:OOAM	7:30 AM	0
2	Rochester NB at Square Lake	8:OOAM	8:30 AM	l/2 S_{FF}
3	696 EB at I-75	7:15AM	8:05 AM	213 S_{FF}

* Effective speed is expressed as a fraction of the free flow speed, S_{FF}

It is important to note that we are modeling direct incident reporting (e.g., cellular phones, police report) for Ah-Scout. This means that an Ah-Scout vehicle becomes aware of the incident in at most two update cycles (i.e., 10 minutes). The background vehicles, however, respond to incidents with a longer delay.

The scenarios designed for the simulation study have another dimension related to the mode under which the Ah-Scout system is operational. Three modes are considered:

- Static mode,
- Dynamic mode based only on historical data, and
- Dynamic mode based on a weighted combination of historical and real-time information.

Given that the targeted analyses address three attributes: (1) market penetration, (2) Ah-Scout routing mode and (3) network conditions, 32 scenarios are considered in the simulation, as depicted in figure 6- 1. These scenarios include the following two *baseline* cases. The first represents the 0% market penetration level without incident, and the second represents the same level with incidents.

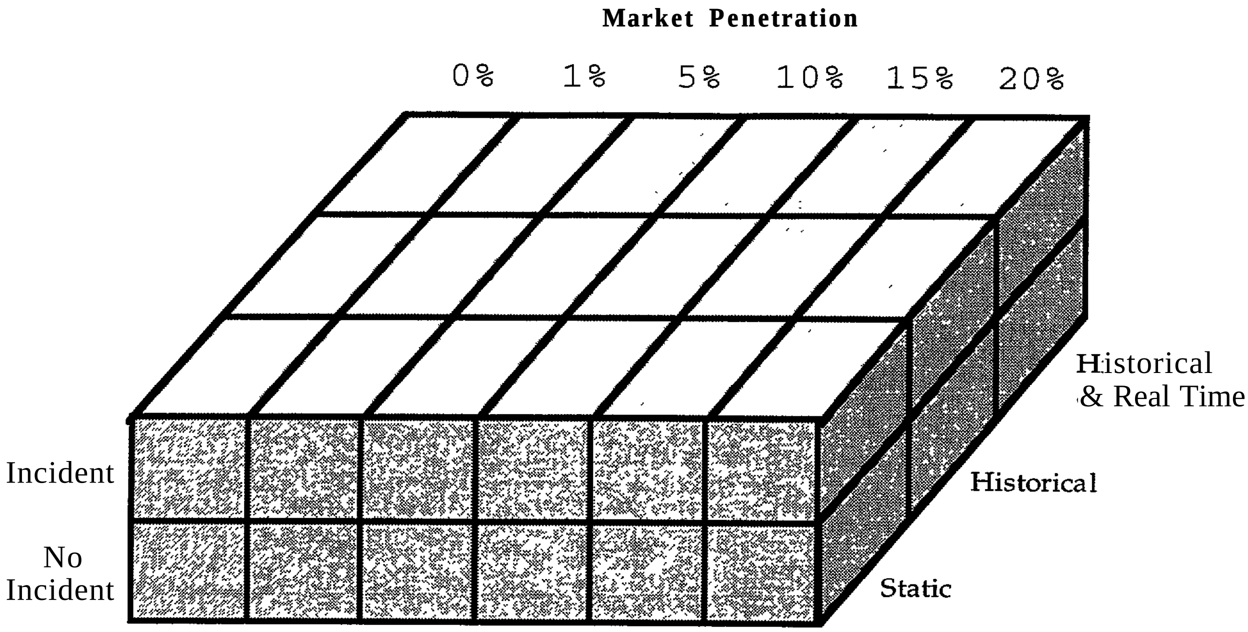

Figure 6-1: Ali-Scout Simulation Scenarios

6.2 Results and Analysis

The simulation model generates a number of Measures Of Effectiveness (MOEs), which are given either as aggregate (or averaged) statistics, or as statistics collected by link, time period, O-D pair, and vehicle type. Two vehicle types are considered: Ali-Scout equipped (or guided) vehicles and non-equipped (or unguided) vehicles.

The following three sections present the MOEs related to the individual vehicles, the system as a whole, and selected areas of the network. Each table shows the result of a particular MOE for a selected set of scenarios. Some MOEs are displayed in the form of charts, in order to compare outcomes across various attributes. To simplify the analysis, the results are summarized and only selected scenarios are discussed in details. However, the detailed simulation results can be found in the appendix.

6.2.1 Individual Performance

The performance of individual vehicles is assessed through the average trip time, average distance traveled, and average speed. The trip time is defined as the time it takes a vehicle to travel from the its origin to its destination. It includes the link travel time, the time spent in the queue at the feeder links (i.e., the links from which vehicles originate) and the time between exit and entrance of consecutive links. These average trip times and the average distance traveled are generated by collecting and averaging the individual MOEs over all vehicles, as well as over unguided and guided vehicles, separately. The average speed is the ratio of the average distance over the average trip time.

The results show that the trip time, distance and speed follow the same general trend. Therefore, the analysis will focus mainly on the trip time. It is important to note that using the system-wide MOEs (i.e., aggregated over all vehicles loaded on the network and all O-D pairs) only gives a general indication on the performance of the Ali-Scout system relative to the baseline. Quantifying the potential benefits, in this case, may not be appropriate given that (1) the beacon area does not cover the entire simulation network, and (2) the simulation scenarios are such that Ah-Scout vehicles may travel between O-D pairs that are not in the FAST-TRAC area. This means that many Ah-Scout vehicles travel under the autonomous mode long before reaching the beacon area.

In order to better estimate the benefits of Ah-Scout, MOEs are also aggregated over some strategic O-D pairs. The targeted O-D pairs in this analysis are such that the vehicles traveling among them are more likely to pass through incident areas. Specifically, the O-D pairs associated with Rochester Road, I-75 and I-696 Freeways. Given the strategic location of the I-75, the analysis will address the performance of vehicles traversing this freeway during their trips.

6.2.1.1 Aggregate MOEs

Table 6-2 and Table 6-3 summarize the results for the scenarios without incident and with incidents, respectively (refer to Table 6-l for a description of the incidents and their locations). For each case, the three Ali-Scout modes are considered: static, dynamic with historical data, and dynamic with historical and real-time data. Also, six levels of market penetration are indicated. Each table shows the average trip time for the unguided vehicles and the Ali-Scout vehicles, as well as the overall average.

A comparison between the average trip time of the unguided vehicles and that of the Ah-Scout vehicles is depicted in Figure 6-2, Figure 6-3 and Figure 6-4 In the static mode (Figure 6-8), Ali-Scout vehicles are routed based on free-flow speed during their entire trip. Although the route computation does not take into account the prevailing network conditions, Ah-Scout vehicles exhibit slightly lower trip times than the unguided vehicles, for some levels of market penetration. This is probably due to the fact that the Ah-Scout routes are not heavily congested by the background traffic. Overall, the performance of the vehicles as a function of the market penetration varies only slightly. This is mainly due to the static nature of the routes used by Ah-Scout vehicles.

Under the historical mode, Ali-Scout vehicles exhibit shorter trip times than the background vehicles for all the levels of market penetration. This can be easily attributed to the frequent update of the Ali-Scout routes and to the use of anticipated link travel times. The increase of effectiveness experienced by the Ah-Scout vehicles, as the market penetration level increases from 1% to 10%, is due to the fact that the historical database is being continuously updated. This means that any additional Ah-Scout vehicles, introduced to the network, benefit from the experience of the existing vehicles. At the level of

Table 6 -2: Average Trip Time (min) in the No-incident Case

Market Penetration	0%	1%	5%	10%	15%	20%
Static						
Unguided	28.6	29.1	28.3	29.1	28.6	28.6
Ali-Scout		28.4	27.9	28.5	28.5	28.9
Overall	28.6	29.1	28.3	29.0	28.6	28.6
Historical						
Unguided	28.6	29.2	29.2	28.3	28.4	28.9
Ali-Scout		28.0	27.6	27.3	27.5	27.8
Overall	28.6	29.2	29.2	28.2	28.3	28.7
Real-time						
Unguided	28.6	29.0	28.3	29.2	28.5	29.0
Ali-Scout		27.4	27.0	27.9	27.5	28.0
Overall	28.6	28.9	28.2	29.1	28.4	28.9

Table 6-3: Average Trip Time (min) in the Incident Case

Market Penetration	0%	1%	5%	10%	15%	20%
Static						
Unguided	28.9	28.8	28.8	28.7	29.1	28.9
Ali-Scout		28.4	28.0	28.5	28.9	29.4
Overall	28.9	28.8	28.7	28.7	29.1	29
Historical						
Unguided	28.9	29.2	28.7	28.4	28.6	28.5
Ali-Scout		28.0	27.2	27.5	27.7	27.4
Overall	28.9	29.2	28.6	28.4	28.5	28.3
Historical & Real-time						
Unguided	28.9	28.6	28.8	28.8	28.5	29.1
Ali-Scout		27.2	27.4	27.4	27.5	28.1
Overall	28.9	28.6	28.7	28.7	28.4	28.9

20%, however, the marginal effectiveness of additional Ali-Scout coverage slightly decreases. This is more likely attributed to the larger number of vehicles using the same type of information, hence creating their own congestion.

The introduction of the Ali-Scout vehicles turns out to be beneficial to the unguided vehicles as well, especially at the levels of 10% and 15%. This is because the more Ali-Scout vehicles are placed on the anticipatory-based routes, the less congested are the background routes. Overall, it seems that the maximum system-wide benefit is achieved around 10-15% market penetration.

When Ali-Scout is in the real-time mode (Figure 6-4), the guided vehicles experience about 5% improvement in trip time over the unguided vehicles, for all the levels of market penetration. However, the system performance varies sporadically as the level of market penetration increases. The reasons behind this phenomenon are not clear. One possible expla-

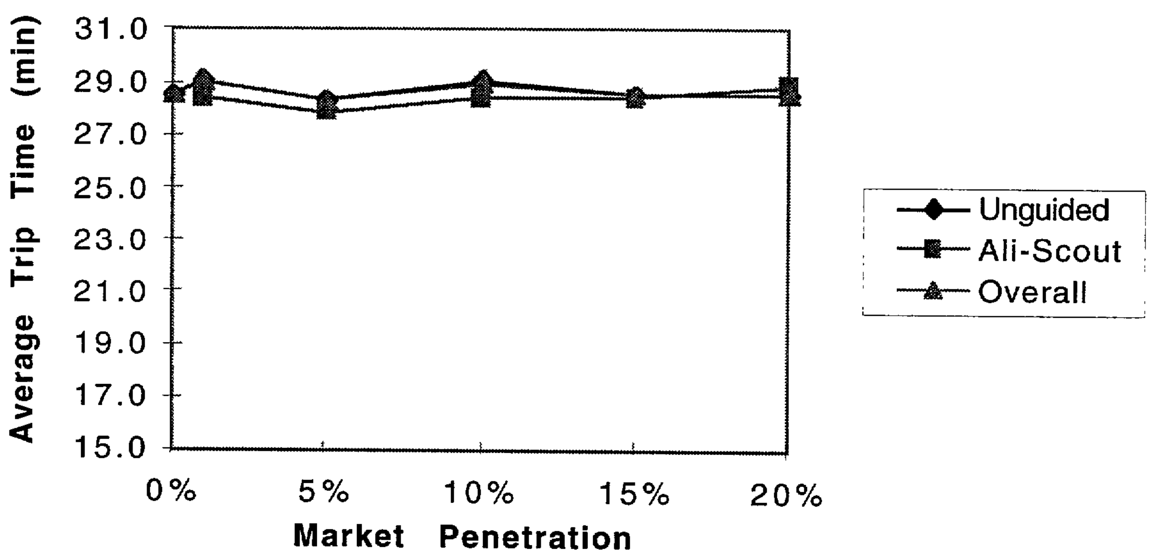

Figure 6-2: Average Trip Time in the No-incident-Static Case

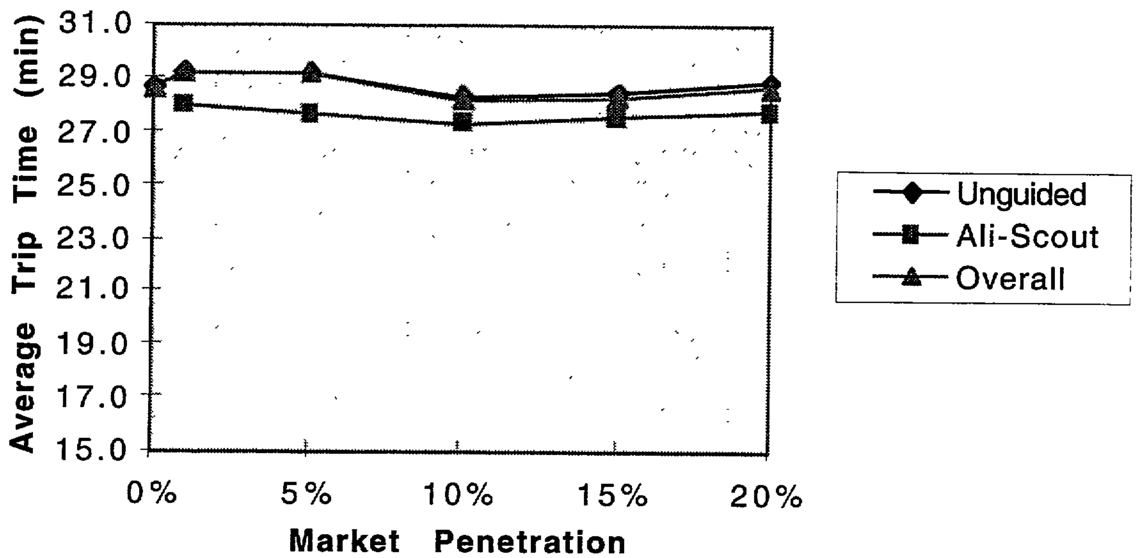

Figure 6-3: Average Trip Time in the No-incident-Historical Case

nation is that no travel time forecasting is used consistent with the anticipatory algorithm. Instead, current real-time data are projected into the future. This problem is compounded by the low beacon coverage in the network.

Overall, the average trip time under the real time mode tends to increase with increasing levels of market penetration. At the level of 20% market penetration, the system performance worsens relative to the baseline case, as observed in the historical case.

From examining the data shown on Table 6-2 and 6-3, the effect of the incidents on the performance of both vehicle types is not apparent. This is because the amount of traffic generated around the incident areas is insignificant relative to the traffic generated throughout the entire network. A more accurate assessment of the incident impact is obtained by focusing on the vehicles that are more likely to encounter an incident. This is elaborated in the following section.

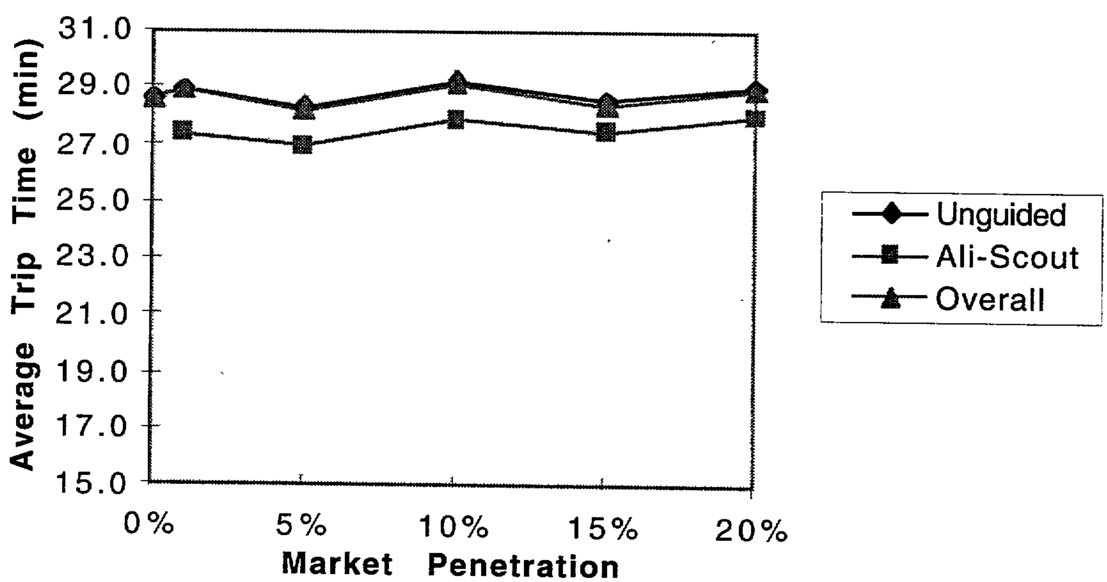

Figure 6-4: Average Trip Time in the No-incident-Real Time Case

6.1.2.1 sELECTED aREA: i-75 fREEWAY

Examining the results shown on Table 6-4, the incident seems to cause more delay for the unguided vehicles than the Ah-Scout vehicles. The delay, measured as the difference in trip times under incident and no-incident cases, is also depicted on Figure 6-5. Notice that Ah-Scout, in this case, is operating under the real-time dynamic mode.

The Ah-Scout vehicles experience shorter trip times than the background vehicles. In the no-incident case, the maximum benefit for Ah-Scout vehicles is attained at the level of 15% market penetration. This benefit amounts to roughly 35% improvement in trip time with respect to unguided vehicles.

Observing Configuration 6-5, one can notice the significant improvement experienced by all vehicles when the level of market penetration is more than 1%. This phenomenon shows the importance of probe coverage in delivering accurate travel time information.

To assess the impact of the operation mode of Ali-Scout, Figure 6-6 illustrates the average trip time of the Ah-Scout vehicles when the system is static, dynamic with historical information, and dynamic with a combination of historical and real time information. Three important phenomena are illustrated. First, in the static case, the Ah-Scout vehicles exhibit a decrease in effectiveness as the level of market penetration increases. Second, the system performs better under the dynamic mode than under the static.

Table 6-4: Average Trip Time of Vehicles Traveling on l-75 (Real-Time Mode)

Market Penetration	0%	1%	5%	10%	15%	20%
No-Incident						
Unguided	45.1	34.5	32.1	31.8	31.3	32.0
Ali-Scout		32.9	33.3	31.0	29.5	30.3
All	45.1	34.5	32.21	31.71	31.0	31.6
Incident						
Unguided	57.2	43.8	39.9	41.7	39.5	40.9
Ali-Scout		42.7	38.5	35.6	33.5	34.3
All	57.2	43.8	39.8	41.0	38.6	39.5
Delay						
Unguided	12.2	9.3	7.7	9.9	8.2	8.8
Ali-Scout		9.8	5.2	4.6	4.0	4.1

It is apparent that the unguided vehicles also benefit from the presence of the guided vehicles. Although their performance is not consistently improving with increasing levels of market penetration, it is clearly better relative to the baseline case. For example, in the incident case, the minimum trip time saving that the unguided vehicles experience is about 25%. This time saving is achieved at only 1% level of market penetration.

Third, in the dynamic mode, the system performs better when real-time information is introduced.

In the static mode, increasing the level of market penetration would only cause a larger number of Ali-Scout vehicles to be assigned on the same routes. Since these routes are not computed based on realistic traffic conditions and because no re-routing is possible, these vehicles end up creating congestion on their routes.

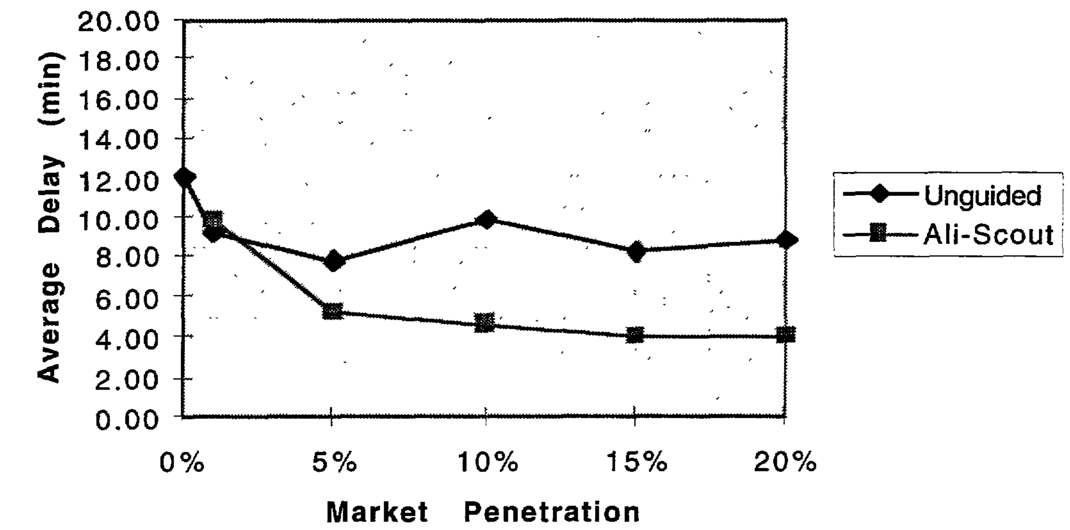

Figure 6-5: Average Delay on I-75 Freeway (Real-Time)

Under the dynamic mode with historical information, the Ali-Scout routes are computed based on experienced or expected traffic conditions. This explains why the guided vehicles experience shorter trip times relative to the static case. However, increasing the level of market penetration does not seem to bring a significant benefit to these vehicles. This is mainly due to the fact that the system is not responsive to prevailing traffic conditions. When real-time information is introduced, the average trip time of Ali-Scout vehicles is significantly reduced. This reduction amounts to about 25% relative to the historical case, for the levels of 10% and 15%. Overall, it seems that the best configuration of the system is attained under the dynamic mode with real-time information, and when the fraction of equipped vehicles is around 15%.

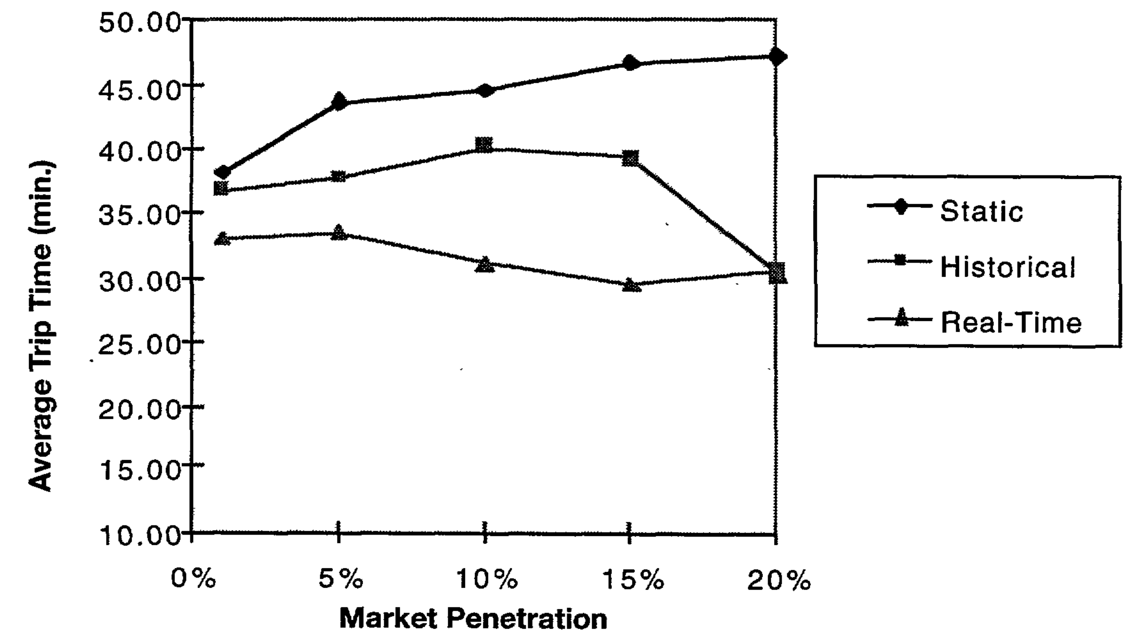

Figure 6-6: Average Trip Time of Ali-Scout Vehicles Traveling on I-75 (no- incident case)

6.2.2 System Perforamnce

The system MOEs address the impacts of Ali-Scout on the operational efficiency of the vehicles and the system infrastructure. They include the following:

- System travel time
- Vehicle Miles Traveled (VMT)

These MOEs can be used to assess some economical and social implications of using such a route guidance system. For example, a decrease in system travel time has the potential benefit of decreasing stress and fatigue among travelers, thus increasing productivity as well as safety. The system travel time is defined as the total link travel time over all vehicles. The difference between travel time and trip time is that the former does not account for queuing (or stop) time, whereas the latter does. The VMT is the total distance traveled by all vehicles. In what follows, we focus on the market penetration analysis when Ah-Scout is under the dynamic mode with historical information.

Table 6-5 reports system MOEs, in the case where Ah-Scout is dynamic using historical information. Figure 6-7 and Figure 6-8 depict the variation of the system-wide travel time and VMT with the level of market penetration, respectively. For each MOE displayed, both the incident and the no-incident cases are considered. After reaching a minimum when the percentage of guided vehicles is between 10% and 15%, the system travel time and VMT exhibit an increasing trend, for both the incident and the no-incident cases. Consistent with the individual performance analysis, the system performance worsens relative to the baseline when the level of market penetration reaches 20%. Under the no-incident case, the system mobility is slightly better compared to the incident case, when the level of market penetration is between 10% and 15%.

Table 6-5: System MOEs under Dynamic-Historical A&Scout

Market Penetration	0%	1%	5%	10%	15%	20%
System Travel Time (1000 veh-hrs)						
No Incident	264.3	266.6	267.7	262.0	262.0	272.2
Inciden t	265.4	267.7	264.3	263.2	264.3	272.2
VMT (1000 veh-miles)						
No incident	10141	10277	10277	10141	10073	10277
Inciden t	*10209*	10277	*10209*	10141	*10209*	10141

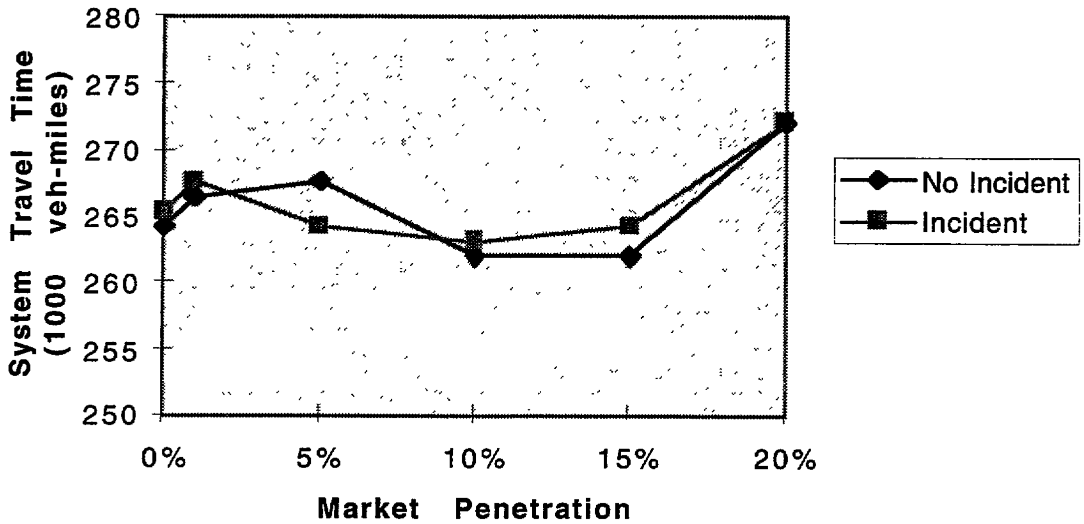

Figure 6-7: System Travel Time with Dynamic-Historical Ali-Scout

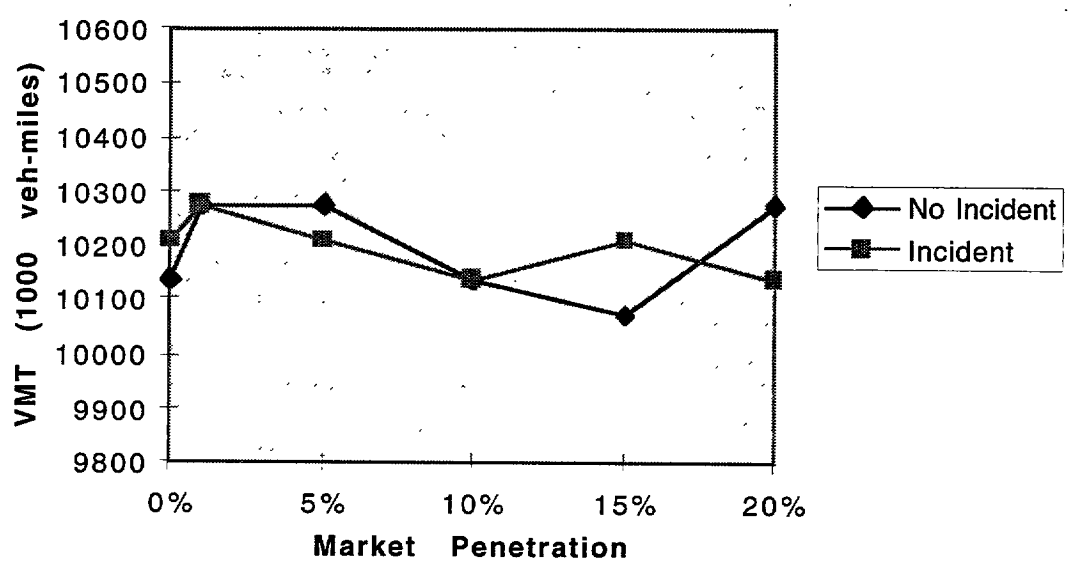

Figure 6-8: System Travel Time with Dynamic-Historical Ali-Scout

7. Conclusion

The simulation framework adopted in this evaluation effort provides many insights on the potential of the Ah-Scout system to improve traffic conditions in a congested urban network. It also sheds some light on the effectiveness of the various modes of system operations. The results highlight the complexity of the effect of Ah-Scout on system performance. Three major factors determine the effectiveness of this guidance system: (1) the beacon coverage; (2) the accuracy of link travel times and (3) the level of market penetration.

Simulation results have illustrated that the effect of Ah-Scout is marginal when the performance of the whole network is evaluated. In this case, the overall benefit of Ah-Scout, in terms of trip time savings, is only around 2% relative to the baseline. This benefit is achieved when Ah-Scout is operating under the dynamic mode, and for both incident and no-incident scenarios. This is not surprising given the beacon area does not cover the entire simulation network, many Ah-Scout vehicles end up traveling under the autonomous mode for a considerable portion of their trip. The effectiveness of Ah-Scout is significant when the analysis focuses on selected areas with a reasonable beacon coverage. Considering only the area around the I-75 freeway the benefit accruing to both guided and unguided vehicles amounts to 30% in trip time savings.

Although the results show some variability across the scenarios, the general conclusion is that the system shows a trend of increasing benefits up to a certain level of market penetration (15% in this case). Beyond this level, the system effectiveness tends to decrease. This implies that the availability of route guidance information may not automatically lead to improvements in traffic conditions. The present low level of market penetration in Oakland County should not be considered a problem. However, if Ali-Scout were to be adopted by more drivers, or should a similar centralized route guidance system catch on with the consumers, then this could become a real limit to individual and collective benefits of route guidance. It is also likely to diminish the market appeal.

We have observed that the reason for the diminishing marginal benefit in the simulation is that the equipped vehicles are taking the same routes and causing their own congestion. In other words, during the update period, vehicles with similar destinations passing by a beacon receive the same route. As the number of equipped vehicles increases, the number of vehicles taking this same route increases, and eventually they start slowing each other down. So it seems that success breeds failure in this example.

However, with a few simple adjustments the above problem can be nearly eliminated. One possible solution is to increase the update frequency while increasing the accuracy of the travel time database. This would be possible as the communication and computational technologies improve. Part of increasing the accuracy would be to update the historical database to take into account the future impacts of recently routed vehicles. The result should be improved routing for each vehicle that passes by a beacon and less beacon originated congestion. Another solution is to implement multi-path routing adjusted to the congestion effects of the routed vehicles. Other techniques may be used, but this problem must be addressed if centralized route guidance is to get beyond the 20% level of market penetration.

It is important to note that there are at least two types of benefits originating from the probing of real-time link travel times in Ah-Scout. The first type of benefit is a source of data for generating an empirically-based historical travel time profile. The second type of benefit is the use of the real-time data as a supplement to the historical database. Probe reports of divergent link travel times are combined with the historical link travel times so that drivers can respond to changes in traffic flow as they travel.

At low levels of market penetration, there may not be enough probe reports to make a sufficiently rapid impact on the link travel time database. The solutions are conceptually simple, but they may not be practical in a centralized route guidance system.

Again, increasing the update frequency of the travel time database is one possible solution. A difference of five minutes can mean a lot in responding to an incident in real time. Another solution is to speed up the response through improvements in surveillance and the synthesis of multiple surveillance sources. In the simulation, we modeled direct incident reporting through, for example, cellular calling. If similar types of incident reports can be used in generating guidance information, then the system will be able to quickly respond to the incidents.

Most of the results in the report have been documented as quantitative improvements in average travel times. It is important to recognize the variability of travel times, which may influence perceptions of benefits. An important distinction should be made between individual driver commute times and average system commute times. For the driver, the average improvement may not be as relevant as the single major incident that was avoided, or even the prospect of avoiding the incident. Many of the commercial airlines recognized the influence of perceptions and revamped their schedules with longer average trip times but better on-time performance. The one bad experience at the airport or waiting for an incident to clear can have devastating impacts from the perspective of the individual consumer. On the other hand, the mounting delay at an incident, and the ability to respond quickly are important factors at the traffic operations center. As a consequence, the average travel time benefits may be viewed as highly significant from a system perspective and may be the most valued aspect of route guidance in responding to an incident. These differences need to be factored in when considering the results produced in this simulation study.

Appendix

AS Route Computation	**None**
As Market Penetration	**0%**
Incident	**No**

Incident Area & Vehicle Type	Travel Time (min) Average	Travel Time (min) Std Dev	Vehicle Count
I-696			
Background	35.33	21.44	2560
Ali-Scout	0.00	0.00	0.00
All	35.33	21.44	2560
I-75			
Background	45.07	23.21	2327
Ali-Scout	0.00	0.00	0.00
All	45.07	23.21	2327
Rochester			
Background	48.96	25.60	4686
Ali-Scout	0.00	0.00	0.00
All	48.96	25.60	4686

System-Wide MOEs

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.60	680595	14.90	31.26
Ali-Scout				
All	28.60	680595	14.90	31.26

AS Route Computation	**None**
As Market Penetration	**0%**
Incident	**Yes**

Incident Area & Vehicle Type	Travel Time (min) Average	Travel Time (min) Std Dev	Vehicle Count
I-696			
Background	36.41	21.80	2560
Ali-Scout	0.00	0.00	0.00
All	36.41	21.80	2560
I-75			
Background	57.23	32.18	2327
Ali-Scout	0.00	0.00	0.00
All	57.23	32.18	2327
Rochester			
Background	48.99	24.66	4688
Ali-Scout	0.00	0.00	0.00
All	48.99	24.66	4688

System-Wide MOEs

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.90	680595	15.00	31.14
Ali-Scout				
All	28.90	680595	15.00	31.14

AS Route Computation	**Static**
As Market Penetration	**1%**
Incident	**No**

Incident Area &	Travel Time (min)		Vehicle
Vehicle Type	Average	Std Dev	Count
I-696			
Background	33.72	20.85	2454
Ali-Scout	32.29	15.42	31
All	33.70	20.79	2485
I-75			
Background	44.45	23.29	2286
Ali-Scout	38.09	17.97	41
All	44.34	23.22	2327
Rochester			
Background	45.09	21.68	3909
Ali-Scout	45.98	18.77	27
All	45.09	21.67	3936

System-Wide MOEs

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	29.12	674325	15.09	31.10
Ali-Scout	28.40	6270	14.80	31.27
All	29.10	680595	15.10	31.13

AS Route Computation	**Static**
As Market Penetration	**1%**
Incident	**Yes**

Incident Area &	Travel Time (min)		Vehicle
Vehicle Type	Average	Std Dev	Count
I-696			
Background	34.10	20.92	2454
Ali-Scout	32.57	15.85	31
All	34.08	20.87	2485
I-75			
Background	57.26	32.20	2286
Ali-Scout	47.49	22.87	41
All	57.09	32.09	2327
Rochester			
Background	45.62	23.18	3909
Ali-Scout	45.65	19.51	27
All	45.62	23.16	3936

System-Wide MOEs

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.82	674325	14.83	30.87
Ali-Scout	28.400	6270	14.70	31.06
All	28.80	680595	14.80	30.83

AS Route Computation	**Static**
As Market Penetration	**5%**
Incident	**No**

Incident Area &	Travel Time (min)		Vehicle
Vehicle Type	Average	Std Dev	Count
I-696			
Background	34.22	21.39	2362
Ali-Scout	36.08	19.29	174
All	34.35	21.26	2536
I-75			
Background	44.46	23.14	2133
Ali-Scout	43.62	23.34	188
All	44.39	23.16	2321
Rochester			
Background	48.04	25.76	4262
Ali-Scout	49.73	20.63	224
All	48.13	25.53	4486

System-Wide MOEs

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.33	651808	14.83	31.41
Ali-Scout	27.90	28787	14.60	31.40
All	28.30	680595	14.80	31.38

AS Route Computation	**Static**
As Market Penetration	**5%**
Incident	**Yes**

Incident Area &	Travel Time (min)		Vehicle
Vehicle Type	Average	Std Dev	Count
I-696			
Background	34.79	21.46	2362
Ali-Scout	37.72	20.33	174
All	35.00	21.40	2536
I-75			
Background	57.42	32.09	2133
Ali-Scout	54.70	29.61	188
All	57.20	31.91	2321
Rochester			
Background	47.98	25.43	4263
Ali-Scout	49.39	20.22	224
All	48.05	25.19	4487

System-Wide MOEs

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.76	651808	14.93	31.15
Ali-Scout	28.00	28787	14.70	31.50
All	28.70	680595	15.00	31.36

AS Route Computation	Static
As Market Penetration	10%
Incident	No

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Travel Time (min) Std Dev	Vehicle Count
I-696			
Background	34.47	21.39	2226
Ali-Scout	35.99	19.69	385
All	34.69	21.16	2611
I-75			
Background	43.61	22.16	2081
Ali-Scout	44.47	23.33	368
All	43.74	22.34	2449
Rochester			
Background	43.92	21.25	3246
Ali-Scout	45.25	19.90	409
All	44.07	21.11	3655

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	29.11	619288	15.10	31.13
Ali-Scout	28.50	61307	14.80	31.16
All	29.00	680595	15.10	31.24

AS Route Computation	Static
As Market Penetration	10%
Incident	Yes

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Travel Time (min) Std Dev	Vehicle Count
I-696			
Background	34.90	21.45	2226
Ali-Scout	36.56	19.51	385
All	35.14	21.19	2611
I-75			
Background	57.36	31.62	2081
Ali-Scout	57.89	30.98	368
All	57.44	31.52	2449
Rochester			
Background	44.57	22.80	3247
Ali-Scout	42.84	18.58	409
All	44.37	22.37	3656

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.70	619288	14.87	31.08
Ali-Scout	28.50	61307	14.70	30.95
All	28.70	680595	14.80	30.94

AS Route Computation	Static
As Market Penetration	15%
Incident	No

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	34.22	21.02	2028
Ali-Scout	36.32	19.44	517
All	34.64	20.72	2545
I-75			
Background	46.08	24.62	2003
Ali-Scout	46.47	25.16	433
All	46.15	24.72	2436
Rochester			
Background	45.38	22.61	3858
Ali-Scout	52.09	21.88	593
All	46.27	22.63	4451

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.58	596756	14.84	31.15
Ali-Scout	28.50	83839	14.60	30.74
All	28.60	680595	14.80	31.05

AS Route Computation	Static
As Market Penetration	5%
Incident	Yes

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	34.35	21.10	2028
Ali-Scout	36.70	19.76	517
All	34.83	20.85	2545
I-75			
Background	60.24	33.50	2003
Ali-Scout	59.91	33.24	433
All	60.18	33.45	2436
Rochester			
Background	45.78	22.71	3858
Ali-Scout	48.76	21.04	593
All	46.17	22.52	4451

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	29.15	596756	15.07	31.02
Ali-Scout	28.90	83839	14.80	30.73
All	29.10	680595	15.00	30.93

AS Route Computation	Static
As Market Penetration	20%
Incident	No

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	35.34	21.73	2001
Ali-Scout	35.99	19.16	717
All	35.51	21.09	2718
I-75			
Background	43.50	23.42	1850
Ali-Scout	46.97	27.63	594
All	44.35	24.56	2444
Rochester			
Background	42.73	21.27	3094
Ali-Scout	42.77	18.66	705
All	42.74	20.81	3799

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.60	559233	14.84	31.13
Ali-Scout	28.90	121362	14.60	30.31
All	28.60	680595	14.80	31.05

AS Route Computation	Static
As Market Penetration	20%
Incident	Yes

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	35.54	21.82	2001
Ali-Scout	36.08	19.27	717
All	35.69	21.18	2718
I-75			
Background	56.65	32.91	1850
Ali-Scout	62.91	39.10	594
All	58.17	34.62	2444
Rochester			
Background	44.29	21.73	3094
Ali-Scout	43.80	19.62	706
All	44.20	21.35	3800

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.89	559233	14.98	31.10
Ali-Scout	29.40	121362	14.70	30.00
All	29.00	680595	14.90	30.83

AS Route Computation	**Historical**
As Market Penetration	**1%**
Incident	**No**

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	34.62	21.30	2580
Ali-Scout	35.26	24.26	27
All	34.62	21.33	2607
I-75			
Background	44.71	22.20	2459
Ali-Scout	36.72	16.68	30
All	44.62	22.15	2489
Rochester			
Background	44.26	21.56	4150
Ali-Scout	40.96	17.81	26
All	44.24	21.54	4176

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	29.22	674325	15.09	30.99
Ali-Scout	28.00	6270	15.20	32.57
All	29.20	680595	15.10	31.03

AS Route Computation	**Historical**
As Market Penetration	**1%**
Incident	**Yes**

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	34.95	21.44	2580
Ali-Scout	34.93	24.85	27
All	34.95	21.48	2607
I-75			
Background	56.85	30.07	2459
Ali-Scout	43.52	23.06	30
All	56.69	30.03	2489
Rochester			
Background	44.42	21.99	4150
Ali-Scout	40.97	21.03	26
All	44.40	21.99	4176

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	29.22	674325	15.09	30.99
Ali-Scout	28.00	6270	15.10	32.36
All	29.20	680595	15.10	31.03

AS Route Computation	Historical
As Market Penetration	5%
Incident	No

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	34.80	21.52	2351
Ali-Scout	36.35	21.42	125
All	34.88	21.52	2476
I-75			
Background	42.55	22.71	2242
Ali-Scout	37.63	17.66	116
All	42.31	22.51	2358
Rochester			
Background	45.96	23.61	4111
Ali-Scout	35.65	18.90	128
All	45.65	23.55	4239

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	29.23	651808	15.10	30.99
Ali-Scout	27.60	28787	15.00	32.61
All	29.20	680595	15.10	31.03

AS Route Computation	Historical
As Market Penetration	5%
Incident	Yes

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	34.94	21.71	2351
Ali-Scout	36.40	21.72	125
All	35.01	21.71	2476
I-75			
Background	54.31	32.08	2242
Ali-Scout	43.53	21.19	116
All	53.78	31.72	2358
Rochester			
Background	44.77	23.34	4111
Ali-Scout	35.50	16.94	128
All	44.49	23.23	4239

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.70	651808	14.93	31.22
Ali-Scout	27.20	28787	14.90	32.87
All	28.60	680595	15.00	31.47

AS Route Computation	Historical
As Market Penetration	10%
Incident	No

System-Wide MOEs

Incident Area &	Travel Time (min)		Vehicle
Vehicle Type	Average	Std Dev	Count
I-696			
Background	35.35	21.15	2318
Ali-Scout	36.01	21.12	270
All	35.42	21.15	2588
I-75			
Background	40.55	22.40	1968
Ali-Scout	39.97	21.84	240
All	40.49	22.34	2208
Rochester			
Background	46.07	22.68	4010
Ali-Scout	44.53	20.71	407
All	45.92	22.51	4417

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.27	619288	14.87	31.56
Ali-Scout	27.30	61307	14.90	32.75
All	28.20	680595	14.90	31.70

AS Route Computation	Historical
As Market Penetration	10%
Incident	Yes

System-Wide MOEs

Incident Area &	Travel Time (min)		Vehicle
Vehicle Type	Average	Std Dev	Count
I-696			
Background	35.63	21.42	2318
Ali-Scout	36.26	21.36	270
All	35.70	21.41	2588
I-75			
Background	52.01	29.13	1968
Ali-Scout	46.03	24.91	240
All	51.36	28.76	2208
Rochester			
Background	45.12	22.70	4010
Ali-Scout	44.63	22.76	407
All	45.07	22.70	4417

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.44	619288	14.87	31.37
Ali-Scout	27.50	61307	14.90	32.51
All	28.40	680595	14.90	31.48

AS Route Computation	**Historical**
As Market Penetration	**15%**
Incident	**No**

System-Wide MOEs

Incident Area &	Travel Time (min)		Vehicle
Vehicle Type	Average	Std Dev	Count
I-696			
Background	34.94	21.17	2252
Ali-Scout	35.72	21.69	385
All	35.05	21.25	2637
I-75			
Background	39.94	20.59	1912
Ali-Scout	39.18	20.71	280
All	39.85	20.60	2192
Rochester			
Background	44.40	22.20	3761
Ali-Scout	41.36	22.59	418
All	44.10	22.26	4179

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	24.91	596756	13.04	31.40
Ali-Scout	27.50	83839	14.90	32.51
All	28.30	680595	14.80	31.38

AS Route Computation	**Historical**
As Market Penetration	**15%**
Incident	**Yes**

System-Wide MOEs

Incident Area &	Travel Time (min)		Vehicle
Vehicle Type	Average	Std Dev	Count
I-696			
Background	35.11	21.41	2252
Ali-Scout	35.65	21.71	385
All	35.19	21.45	2637
I-75			
Background	51.12	28.18	1912
Ali-Scout	46.30	25.61	280
All	50.51	27.91	2192
Rochester			
Background	46.06	24.59	3762
Ali-Scout	40.81	22.73	418
All	45.53	24.46	4180

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.61	596756	14.97	31.39
Ali-Scout	27.70	83839	15.00	32.49
All	28.50	680595	15.00	31.58

AS Route Computation	Historical
As Market Penetration	20%
Incident	No

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	33.73	20.39	2280
Ali-Scout	18.73	24.78	30
All	33.54	20.52	2310
I-75			
Background	39.21	21.38	1989
Ali-Scout	98.59	53.46	84
All	41.62	26.30	2073
Rochester			
Background	48.64	25.23	4160
Ali-Scout	53.61	37.58	113
All	48.78	25.64	4273

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.98	559233	15.00	31.06
Ali-Scout	30.30	121362	14.60	28.91
All	29.20	680595	14.90	30.62

AS Route Computation	Historical
As Market Penetration	20%
Incident	Yes

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	33.96	20.52	2280
Ali-Scout	28.84	44.40	32
All	33.89	21.05	2312
I-75			
Background	50.68	29.21	1989
Ali-Scout	97.64	66.86	52
All	51.87	31.62	2041
Rochester			
Background	48.62	25.77	4160
Ali-Scout	52.90	35.04	113
All	48.74	26.07	4273

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.81	559233	14.90	31.03
Ali-Scout	30.10	121362	14.50	28.90
All	29.10	680595	14.80	30.52

AS Route Computation	**Hist/Real**
As Market Penetration	**1%**
Incident	**No**

Incident Area & Vehicle Type	Travel Time (min) Average	Travel Time (min) Std Dev	Vehicle Count
I-696			
Background	31.79	16.84	1217
Ali-Scout	35.07	35.23	5
All	31.81	16.96	1222
I-75			
Background	32.91	16.33	846
Ali-Scout	146.27	33.38	5
All	33.58	18.62	851
Rochester			
Background	38.91	21.64	1111
Ali-Scout	115.51	56.20	12
All	39.73	23.65	1123

System-Wide MOEs

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	29.05	674325	15.09	31.17
Ali-Scout	37.30	6270	20.70	33.30
All	29.10	680595	15.10	31.13

AS Route Computation	**Hist/Real**
As Market Penetration	**1%**
Incident	**Yes**

Incident Area & Vehicle Type	Travel Time (min) Average	Travel Time (min) Std Dev	Vehicle Count
I-696			
Background	31.81	16.86	1217
Ali-Scout	23.40	9.72	6
All	31.76	16.84	1223
I-75			
Background	41.57	22.43	846
Ali-Scout	49.08	27.45	5
All	41.61	22.47	851
Rochester			
Background	39.80	22.82	1111
Ali-Scout	43.99	23.90	17
All	39.86	22.84	1128

System-Wide MOEs

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.62	674325	14.76	30.94
Ali-Scout	27.20	6270	14.80	32.65
All	28.60	680595	14.80	31.05

AS Route Computation	**Hist/Real**
As Market Penetration	**5%**
Incident	**No**

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	31.82	16.89	1204
Ali-Scout	35.25	17.61	35
All	31.92	16.92	1239
I-75			
Background	34.40	17.50	821
Ali-Scout	41.64	21.20	59
All	34.89	17.86	880
Rochester			
Background	38.39	21.89	1083
Ali-Scout	46.46	25.64	68
All	38.87	22.21	1151

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.63	651808	14.83	31.09
Ali-Scout	29.30	28787	15.30	31.33
All	28.70	680595	14.80	30.94

AS Route Computation	**Hist/Real**
As Market Penetration	**5%**
Incident	**Yes**

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	31.76	17.07	1204
Ali-Scout	30.35	14.57	35
All	31.72	17.00	1239
I-75			
Background	41.07	22.22	821
Ali-Scout	37.42	18.45	59
All	40.83	22.01	880
Rochester			
Background	40.87	24.57	1083
Ali-Scout	42.44	26.95	68
All	40.96	24.72	1151

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	29.19	651808	15.10	31.03
Ali-Scout	27.80	28787	15.10	32.59
All	29.10	680595	15.10	31.13

AS Route Computation	**Hist/Real**
As Market Penetration	**10%**
Incident	**No**

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	32.08	16.69	1174
Ali-Scout	31.38	16.91	102
All	32.02	16.70	1276
I-75			
Background	33.51	15.96	754
Ali-Scout	33.35	17.56	79
All	33.49	16.12	833
Rochester			
Background	38.28	20.97	1094
Ali-Scout	38.34	22.45	121
All	38.29	21.12	1215

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.87	619288	15.10	31.38
Ali-Scout	28.50	61307	15.20	32.00
All	28.90	680595	15.10	31.35

AS Route Computation	**Hist/Real**
As Market Penetration	**10%**
Incident	**Yes**

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	32.71	17.56	1174
Ali-Scout	30.80	16.53	102
All	32.55	17.48	1276
I-75			
Background	40.12	21.91	754
Ali-Scout	34.66	19.32	79
All	39.60	21.73	833
Rochester			
Background	39.03	21.96	1095
Ali-Scout	35.79	20.25	121
All	38.71	21.82	1216

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.64	619288	14.87	31.15
Ali-Scout	27.40	61307	14.90	32.63
All	28.50	680595	14.90	31.37

AS Route Computation	Hist/Real
As Market Penetration	15%
Incident	No

Incident Area &	Travel Time (min)		Vehicle
Vehicle Type	Average	Std Dev	Count
I-696			
Background	31.37	16.34	1054
Ali-Scout	33.26	18.62	168
All	31.63	16.68	1222
I-75			
Background	32.33	15.61	771
Ali-Scout	33.30	17.47	129
All	32.47	15.89	900
Rochester			
Background	38.66	21.53	1088
Ali-Scout	35.57	19.92	127
All	38.33	21.39	1215

System-Wide MOEs

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.92	596756	15.11	31.34
Ali-Scout	28.30	83839	15.10	32.01
All	28.90	680595	15.10	31.35

AS Route Computation	Hist/Real
As Market Penetration	15%
Incident	No

Incident Area &	Travel Time (min)		Vehicle
Vehicle Type	Average	Std Dev	Count
I-696			
Background	32.05	16.92	1054
Ali-Scout	32.77	18.03	168
All	32.15	17.08	1222
I-75			
Background	40.31	21.81	771
Ali-Scout	35.17	18.35	129
All	39.57	21.42	900
Rochester			
Background	38.70	22.36	1088
Ali-Scout	34.94	21.02	127
All	38.31	22.26	1215

System-Wide MOEs

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.38	596756	14.87	31.44
Ali-Scout	27.30	83839	14.90	32.75
All	28.20	680595	14.90	31.70

AS Route Computation	Hist/Real
As Market Penetration	20%
Incident	No

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	32.17	17.02	1025
Ali-Scout	57.45	50.83	172
All	35.80	26.42	1197
I-75			
Background	33.13	15.50	721
Ali-Scout	62.61	38.84	203
All	39.61	25.84	924
Rochester			
Background	38.15	21.40	1002
Ali-Scout	56.44	34.31	257
All	41.88	25.67	1259

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.91	559233	14.98	31.08
Ali-Scout	35.30	121362	19.00	32.29
All	30.10	680595	15.70	31.30

AS Route Computation	Hist/Real
As Market Penetration	20%
Incident	No

System-Wide MOEs

Incident Area & Vehicle Type	Travel Time (min) Average	Std Dev	Vehicle Count
I-696			
Background	32.23	17.06	1025
Ali-Scout	57.34	44.32	169
All	35.78	24.59	1194
I-75			
Background	42.76	22.07	721
Ali-Scout	67.91	44.51	198
All	48.18	30.26	919
Rochester			
Background	39.31	22.54	1003
Ali-Scout	56.86	39.94	242
All	42.72	27.70	1245

Vehicle Type	Travel Time (min)	Vehicle Count	Average Distance (mi)	Average Speed (mph)
Background	28.85	559233	14.88	30.94
Ali-Scout	35.20	121362	18.80	32.05
All	30.00	680595	15.60	31.20

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