Harnessing the Power of Microscopic Simulation to Evaluate Freeway Service Patrols

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ABSTRACT

Public agencies have been increasing their use of Freeway Service Patrols (FSPs) to help with incident response and motorist support. FSPs are also a useful tool in detecting and verifying incidents, thus minimizing the duration and the impacts on traffic. A quantitative assessment of the impacts on incident duration of different FSP service strategies, including various FSP vehicle headways and dispatch policies, will provide guidance and additional motivation for the widespread deployment of such systems. Using the microscopic simulation software PARAMICS, this work evaluated the benefits of FSPs in reducing incident duration, which in turn has a considerable positive effect on total vehicle hours of travel during an incident. The authors applied PARAMICS to simulate various strategies related to FSP operations through an Application Programming Interface (API). PARAMICS is suitable for applying a combination of simulation modules, such as random spatial and temporal incident generation, and modeling FSP service headway and restrictions of FSP assignments in the network. Analysis of the simulation revealed that both dispatch policies and the headway between FSP vehicles affected the incident response times and consequently the duration of incidents as well as vehicle hours of travel. The effects of different dispatch policies diminished as the headways of FSPs increased. Results also revealed that as the severity of incidents (in terms of number of lanes blocked) increases the benefits of FSP programs increases, by reducing delay through faster detection, response and clearance.
INTRODUCTION

Highway incidents involving disabled vehicles, cargo spills, and crashes cause property damage, physical injuries, and fatalities. In 2002, the Fatality Analysis Reporting System identified 42,815 highway fatalities (1). If these incidents had been detected and verified more quickly, medical assistance would have been able to provide faster treatment, thus possibly saving many lives that were regrettably lost. Highway incidents also cause excessive traffic backups, which result in motorist delay, business loss, additional fuel consumption, vehicle emissions, and possible secondary crashes. The Texas Transportation Institute estimated that since 2000, the cost of highway congestion has already aggregated to $67.4 billion each year, which was an increase of 400% since 1982 (2). According to the Federal Highway Administration, nearly 60 percent of all urban freeway delay is due to incidents, a value that also increases each year (3).

Because traffic incidents such as crashes are inherently unpredictable, transportation agencies have great challenges in reducing their adverse effects through real-time traffic management. Incident management comprises four distinct yet correlated phases: detection, verification, response, and clearance (4). When incidents occur, each component plays a crucial role in achieving the objective of restoring the facility to normal operating conditions as quickly as possible. Effective incident detection and verification is important for the timely and appropriate initialization of real time traffic management. The time necessary to clear an incident depends on the characteristic of an individual incident and the resources available to clear it, which leaves little space for improvement. However, the time required for detecting, verifying and responding to a particular incident can be significantly reduced by combining these three phases.

The Freeway Service Patrol (FSP) program, classified as a component of Intelligent Transportation Systems (ITS), uses roving vehicles to aggressively seek traffic incidents by patrolling a selected corridor. FSPs combine incident detection, verification, and response to reduce the total duration of incidents by providing a timely response to any abnormal events. FSPs are also able to manage the incident scene, clear roadways, and provide traffic status information for motorists through Variable Message Signs (VMS) and/or Highway Advisory Radios (HARS), and by initiating appropriate multi-agency incident management actions. Such actions might include notifying other incident response units and traffic management centers (5). FSPs also help to smooth traffic flow and improve highway safety by aiding stranded motorists and assisting in crash clearance.

Freeway Service Patrols are nationally recognized as one of the most cost-effective ITS strategies (6). Their abilities to shorten response times and their expertise in dealing with incidents result in substantial decreases in incident durations. FSPs are essential for managing traffic and providing motorist assistance and security, reduction in incident-induced delay, improved safety, lower fuel consumption, and lower emissions. Due to their large benefit-to-cost ratios, the use of FSPs has expanded rapidly nationwide since their inception in Chicago in the 1960s (5).

Deployment strategies of FSPs include the following: 1. operating patrol units waiting for incident calls at a static point and 2. patrolling the freeway in search of incidents. The first strategy may be justified if there is an automatic incident detection system (7). The second strategy includes assigning the FSP vehicles to patrol the entire responding area, an equal and
fixed length of freeway, or an unequal and fixed length of freeway. Early studies have used sophisticated mathematical programming methods, such as probabilistic modeling (8, 9) or Mixed Integer Programming (MIP) (10) to optimally assign FSPs on the freeway based on local traffic conditions and incident characteristics.

There are three dispatching policies reported: first-come-first-serve, nearest neighbor, and highest-priority (11). The implementation of an appropriate policy is an essential issue in case of multiple incidents occurring at the same time. Moreover, if the policy and geometry allows, the FSP can travel on the shoulder or median to reach the incident location, and if the FSP detects an incident on the other side the freeway, it can turn around at the next exit or median crossing (7).

Some studies focused on evaluating the FSP by performing cost-effectiveness or cost-benefit analyses using actual before and after deployment data. One 1995 study reported that employing a FSP system in Colorado reduced incident duration by 8.6 to 10.5 min and reduced average delay by 71 to 98 vehicle-hours per incident (12). In 1998, Skabardonis et al. determined the benefit to cost ratio of a FSP program in Hayward, California was greater than 5:1 (13). In 1999, a study showed the benefit-cost ratio of the Hoosier helper freeway service patrol program (Indiana DOT) at 4.71:1 for daytime only operation and 13.28:1 for 24 hr. operation (14).

Another study of the Penn-Lincoln Parkway Service Patrol program in Pennsylvania found substantial reductions in incident response and clearance times (15). In 2005, the Florida Road Ranger FSP system was estimated to have benefit to cost ratios range from 2.3:1 to 41.5:1 in different districts (16). These studies are consistent with a 1998 study of 53 FSP in 22 states that found benefit-cost ratios ranging from 2:1 to 36:1 in the U.S. (5).

Despite such positive findings, several factors make benefit-cost studies of FSPs difficult. The field data collection process is time consuming and expensive, and evaluations can only be conducted after a system is implemented. Traffic simulation software offers a solution to these issues.

Some researchers have used traffic simulation to access the operational performance of FSPs. In 2002, Pal and Sinha developed a mesoscopic simulator to demonstrate that a well-validated model would be useful for determining the efficacy of FSP and helping improve the effectiveness of the FSP program (7). In 2003, Ozbay and Bartin applied the Arena simulator to model the process of different incident management strategies (11). This study did not specifically enumerate the impacts on traffic, but rather studied the operational efficiency of the incident management process. The use of behavior-based microscopic traffic simulators can improve the accuracy by simulating interaction of each vehicle in the network.

Because of these advantages, microscopic traffic simulation has been more widely used to evaluate and improve the effectiveness of ITS implementation, including incident management strategies. A 1997 study used microscopic simulation to measure the impacts of the Massachusetts Motorist Assistance Program (17). In 1998, Anderson and Souleyrette developed a microscopic simulation model as a decision support tool for implementing incident management program (18). A 2002 study, examining the benefits of varying combinations of ITS applications using the microscopic simulation model AIMSUN2, found that it was more cost-effective to deploy each technology in isolation rather than to integrate several technologies together (19). A 2004 study applied the PARAMICS microscopic traffic simulator to evaluate potential ITS strategies on a corridor in Irvine California (20). Another study simulated the impacts of various incident management strategies such as VMS and sensors using PARAMICS, and assessed their economic impacts (21). Recent studies have also integrated benefit-cost analyses and microscopic simulation. In 2004, a study of the Minnesota DOTs Freeway Incident
Response Safety Team (FIRST) program used the popular microscopic traffic simulation program CORSIM and estimated a benefit-to-cost ratio of 15.8:1 for this program (22).

Compared with other methods, simulations allow evaluation of different strategies in a cost-effective fashion. Furthermore, microscopic simulations enables detailed and realistic FSP program modeling, eliminating the need for collecting traffic and event data after the implementation of a particular strategy. However, there has not been much effort to use the versatility of state of the art microscopic simulation programs to estimate the benefits of FSP programs in terms of reducing incident related delays. The objective of this research was to use a microscopic simulation modeler to evaluate the benefits of FSPs in South Carolina. The primary measures of performance (MOEs) include the arrival time of the FSP and total vehicle hours of travel during an incident. The arrival time, which is the time difference between the incident occurrence and the arrival of the FSP, is a direct output of the microscopic simulator.

METHODOLOGY

This section discusses the approach and justifications used for building a test network, generating randomly occurring incidents, and simulating FSPs. Figure 1 shows the entire process of simulating traffic and incidents, and the interaction with the freeway services patrol program module. The framework developed for this research work was comprised of three components: traffic simulation, incident generation, and freeway service patrol. The traffic simulation model was developed in PARAMICS Modeler, and the other two components connect to the traffic simulation through the interface provided by PARAMICS Programmer. Upon incorporating the functionality and information of each module, the arrival time of the first FSP was determined, and other MOE statistics were generated.
The arrival time of the first FSP depended on the random location of the incidents in the selected network, the FSP vehicle headway, the FSP dispatch policy, and traffic conditions. While the average FSP headway and policy was controlled, the randomness of the other factors, such as location of incidents, start time of incidents and traffic conditions, were randomly generated.

**Traffic simulation**

The microscopic traffic simulation model was used to create a realistic traffic environment to test the deployment influence of FSPs. Since this study would be extremely expensive to field-test, traffic simulation offers an efficient opportunity to collect extensive amounts of information in a controlled environment that accurately reflects real-world traffic conditions.

PARAMICS traffic simulation software (23) was used to model the traffic flow of the test network in South Carolina. PARAMICS is a time-step, behavior-based microscopic traffic simulation model, which can incorporate detailed network and traffic control information to provide a realistic estimate of traffic operation conditions. Many different Driver Vehicle Units
(DVUs) including FSPs interact in the simulation model to realistically represent the traffic conditions in the real world. DVUs allow a reasonable distribution of different vehicle and driver types, e.g. sports cars with excellent acceleration characteristics or cautious drivers awaiting a large gap in traffic. An accurate representation of these interactions is especially important during traffic incidents, when the FSPs must travel through congested road sections. Since the FSPs were assigned their own DVU the model allowed FSPs to use the shoulders to reach the incident scene, but at a slower speed of 35mph. PARAMICS also provided quantifiable measurements of statistics such as average speed, flow rate and network delay.

The Application Programming Interface (API) is an add-on module which allowed users to modify many features of the underlying PARAMICS models. The API also allowed the development of advanced traffic control strategies such as the FSP routing. This study applied an API to randomly generate incidents and simulate the realistic operation of a freeway service patrol. The following sections discuss these API implementations.

**Test Network**

The I-85 corridor in Greenville, South Carolina was used as the study network, containing approximately 11 miles of freeway and 6 interchanges. Figure 2 shows the network as it appears in the traffic simulation program. As an urban freeway, the traffic volume and incident rates are higher than surrounding freeway sections in the state.

After site selection, the research team used the PARAMICS microscopic traffic simulation software to build, calibrate, and validate the roadway network. Network building began by collecting various data including geometry, traffic control, and traffic volume. The geometric layout data for the roadway network was obtained from South Carolina Department of Natural Recourses in GIS format. The road network sketch was built using the software Shape to PARAMICS (S2P) \(^{(24)}\), which converted the shape-file data into a PARAMICS network file. This conversion tool allowed the accurate scaling of the roadway network. Next, aerial photos from multiple sources and information collected from site visits were used to verify correct geometric conditions, such as number of lanes, lane widths, lane allocation, and curvature.

The research team requested and received the traffic volume and incident data from the South Carolina Department of Transportation (SCDOT), local planning organizations, and the South Carolina Department of Public Safety. The SCDOT provided hourly and average daily traffic count data, traffic signal timing data, and incident location and severity history. The local planning organizations provided a planning model for use in predicting the travel origins and destinations of the observed network traffic. Other data needs such as speed limits, rights of way, and stripping, were met through observation during site visits. All of this information was used to build the traffic simulation model in PARAMICS.

The calibration process compared the simulation volume output to the obtained traffic count data, as well as the animation features of simulation to the authors’ field observation of traffic operation at the site. The validation process compared queue lengths and travel times collected during the site visits to those produced by the simulation model.
Figure 2. PARAMICS Layout of the Test Network

The calibrated and validated PARAMICS model produced good agreement with the field data. The overall simulated traffic volumes are within 1% of the observed, and the highest individual count station error was no more than 10%. The distributions of the drivers’ aggression factor and awareness factor were found to have the biggest effect on the traffic condition in terms of travel time. Because the majority of the drivers in the study network were commuters, they were more familiar and aggressive than other driver populations. In addition, the mean target headway and mean reaction time were another two important parameters that affect the PARAMICS models. After many iterations and adjustments to the road network and driver behavior parameters, the simulation model accurately reflected the observed travel times within one percent and matched observed queue length.

The average annual daily traffic was converted to hourly volume according to the typical traffic volume profile of an average weekday. The traffic scenario for this study was PM peak period during an average weekday. The simulations were started at 4:00 PM and allowed at least a half an hour of warm up time. The peak hour was between 5:00-6:00 PM.

Incident Generation

Three years of freeway incident data was geocoded in TransCAD, a GIS based transportation planning software. This GIS software, combined with the statistical analysis, determined the spatial and temporal distribution of the incidents. It should be noted that the incident data only included reported incident and non-reported incident data was not available.
This distribution, in turn, provided information to the random incident generator to allow randomness while simultaneously illustrating the most representative incident locations. Since the authors concentrated on demonstrating the benefits of the exiting FSP program, only incidents occurring during the peak hour and at the highest occurrence rate locations were examined, because these incidents have the most severe impacts on the traffic.

Because arrival times vary due to the distance between the incident site and the FSP unit at the time the incident occurred, a discrete random number generator was used to determine incident start time after the warm-up period. The simulation model set the incident occurrence at any time point during an average FSP headway period, which is the mean time gap between two consecutive freeway service patrols. This approach considers all of the possible locations a FSP could be when an incident occurred in the network.

Incidents were generated randomly along two quarter mile segments that showed the highest and second highest histories of incident occurrence rate (Exit 48 and Exit 51). Through PARAMICS Programmer’s API interface, the traffic simulator decided various incident occurrence times and locations accounting for the effects of different traffic and incident scenarios. Measures of performance such as arrival time and total vehicle hours of travel were recorded and evaluated under those various situations.

Two kinds of incidents were simulated, one was a minor incident with one lane blocked and the other was a moderate incident with two lanes blocked. Some sources reported a minimum time between 14 to 25 minutes \((13, 17, 25)\) to detect and verify the incident by other means (e.g. 911 emergency calls and surveillance cameras). The authors assumed that, on average, 20 minutes were needed for incident detection and verification without using a FSP. To estimate on-scene arrival, a national average of 9.5 minutes response time was used. Therefore, a 20 minutes incident detection and verification time and a 9.5 minutes response time \((26)\) were used for both incident types. After detection and verification, 11 minutes and 40 minutes were used as the average clearance time for minor and moderate incidents, respectively. These incident clearance times were determined by the historical reported incident clearance times obtained from the TMC located in Greenville, SC.

**Simulating Freeway Service Patrol**

The traffic simulator released the FSP into the simulation network as predetermined route vehicles that follows the main freeway links. The FSPs began patrolling from the southern end of the network, traveled to the northern end of the study network and then turned back towards the southern end. The FSP circulated along the network along the aforementioned route and the actual headway varied with the real time traffic conditions. A random time variance ranging from one to three minutes was inserted to the schedule of each FSP to account for randomness in the service patrol’s travel pattern. In this simulation study, the FSP vehicle units made the decision when to use shoulder based on link congestion. If the level of service of the left most lane was F, then FSPs chose to travel on the shoulder, where the travel speed was at most 35 mph, as suggested by the expert opinion of the South Carolina State Highway Patrol. Otherwise, FSPs traveled on the normal travel lanes. This study examined two FSP dispatching policies in the simulation network.

- **Policy A:** required all FSPs to remain on assigned routes. According to this policy, all FSPs always followed the predetermined patrol route, even if an incident was detected on the other side of the freeway. The FSPs cleared the incidents once they observed them on their route.
- Policy B: allowed FSPs to turn around at the closest interchange to reach a visually identified incident. Similar to policy A, incident clearance began upon incident scene arrival. The FSPs did, however, turn around to respond to detected incidents located on the other side of the freeway.

To implement Policy B FSP service, several new FSP routes were created starting at the beginning of each off-ramp that provided a possible location for the FSP to turn around while responding to the incidents that occurred on the opposite direction. When a FSP observed an incident that occurred on the opposite direction, the value of a turn around flag became TRUE. Once the FSP approached a possible turn around location, it checked the value of turn around flag to make the decision whether it needs to change the travel direction or not. If the answer was TRUE, the original FSP was removed from the network and a new FSP was released from that location at the same time. This new FSP traveled through the interchange along the predetermined response route and proceeded directly to the incident location.

Both policies considered the first arriving FSP as the arrival time, regardless of the FSPs initial route. For each simulation run, FSPs followed the pre-determined dispatch policy, A or B, to provide service to freeway motorists. These services were input into PARAMICS Programmer through the API interface and using the PARAMICS public transit line feature.

**Output Arrival Time**

Once the three modules were incorporated, the simulation was performed to generate the FSP arrival time samples for different incident scenarios. The arrival time was calculated as the time difference between the time the incident occurred and the time the first FSP arrived on-scene.

**ANALYSIS**

**Historical Incident Data**

The spatial analysis of incident occurrence with respect to interchanges in the freeway network indicated that Exit 48 and Exit 51 were the two interchanges with the highest number of incidents between 2002 and 2004. For this reason, incidents were simulated to randomly occur at these two interchange areas to demonstrate the benefits of a FSP along I-85 in Greenville, South Carolina.

Figure 3 shows an example of the freeway network geocoded with incidents for 2003. There were 399 incidents in the study network in that year; 79 incidents resulted in fatalities and injury, while the other 320 were property damage only (PDO) incidents. Due to the high frequency of incidents along this section of freeway, incident data of all three years was not shown in Figure 3 for clarity. The locations of exits 48 and 51 along the freeway network are also shown in Figure 3.
The incident duration was determined as the sum of incident detection, verification, response, and clearance time. The total of detection verification and response is 29.5 minutes for no FSP program scenario and this value varies for the scenarios with FSP programs depending on the FSP headway and dispatch policy. Each simulated incident used a specific value for clearance times both with and without FSP program scenarios. Different clearance times were applied in the simulations based on the reported incident data received from the Greenville, South Carolina Traffic Management Center.

**FSP Response**

Average FSP arrival times were examined in two dimensions: policy type and average FSP headway. TABLE 1 shows the simulation results of the average arrival time in seconds of the first FSP at different incident locations, for an incident with one lane blocked, with different dispatch policies and the FSP headways. The FSP arrival times of policy B were always lower than policy A for random occurrence of incidents at the two interchanges, suggesting better benefits with flexible routing of FSP. This advantage decreases when FSP headways decrease.
TABLE 1. Average Arrival Time of FSP (in seconds)

<table>
<thead>
<tr>
<th>ID</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Headway between FSP vehicles</td>
<td>30 min</td>
<td>15 min</td>
<td>10 min</td>
</tr>
<tr>
<td></td>
<td>Dispatch Policy A</td>
<td>951</td>
<td>481</td>
<td>353</td>
</tr>
<tr>
<td></td>
<td>Dispatch Policy B</td>
<td>503</td>
<td>381</td>
<td>299</td>
</tr>
</tbody>
</table>

FIGURE 4 shows the timesavings that a FSP provided compared to this estimated 20-minute arrival time for no FSP. As the FSP headway decreased, the arrival time decreased, the incident duration saving increased, and the effects of the dispatch policy diminished.

![Figure 4](image-url)

Figure 4. Incident Duration Saving for Different FSP Dispatch Policy

The authors conducted a least significant difference (LSD) evaluation. In this evaluation, if the mean difference in arrival times of each pair of FSP headway was larger than the LSD, then there was a significant difference between these two groups. TABLE 2 shows a decision of “Yes” when a significant difference between the groups was found for policy A. Notice that 1 FSP represents a 30 minute headway, 2 FSPs represents a 15 minute headway, 3 FSPs represents a 10 minute headway, and 4 FSPs represents a 7.5 minutes headway. Results showed that the FSP average arrival time with 30 minutes in the network significantly differed from the arrival time with 15 minutes, therefore increasing from 1 to 2 FSPs creates a significant difference in arrival time. The same was found when FSP headway changed from 10 minutes to 7.5 minutes.
The statistical analysis also found no significant difference in the timesavings when FSP headway changed from 15 minutes to 10 minutes. While Table 2 only displays the results for FSP with policy A, similar results were found when analyzing the arrival time change with policy B.

**TABLE 2: Comparison of Arrival Time Savings with Different FSP Fleet Size**

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Mean Diff</th>
<th>LSD</th>
<th>Decision</th>
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<tbody>
<tr>
<td>1-2</td>
<td>470</td>
<td>331.39</td>
<td>YES</td>
</tr>
<tr>
<td>2-3</td>
<td>128</td>
<td>159.11</td>
<td>NO</td>
</tr>
<tr>
<td>3-4</td>
<td>152</td>
<td>114.57</td>
<td>YES</td>
</tr>
</tbody>
</table>

After understanding which changes in FSP numbers were significant, a T-test was conducted using a 95 percent confidence level to determine the arrival time savings range for each change. The results of the T-test for the incidents that were simulated with policy A and B are presented in FIGURE 5 and FIGURE 6, respectively. The squares represent the sample mean arrival time savings and the limits of the solid lines represent the range of the expected arrival time savings with 95 percent confidence. As previously discussed, a 20-minute arrival time for the FSP was assumed for simulations with no FSP program. While the lower limits of time savings were negative when changing between 2 and 3 FSPs, indicating the change in the number of FSPs might cause a loss in time savings or increased arrival time, there were no significant changes in time savings when the number of FSPs changed from two to three, as shown in TABLE 2.

![Incident Arrival Time Savings Range with FSP Vehicle Headway Changes for Dispatch Policy A](image)

**FIGURE 5. Arrival Time Savings Range with FSP Vehicle Headway Changes for Dispatch Policy A**
The highest rate of time savings for policy A was found when increasing the number of FSPs in the network from one to two. The highest rate of time savings for policy B was found when increasing the number of FSPs from zero to one.

![Arrival Time Savings Range with FSP Vehicle Headway Changes for Dispatch Policy B](image)

**FIGURE 6. Arrival Time Savings Range with FSP Vehicle Headway Changes for Dispatch Policy B**

The total incident duration of different FSP programs is shown in Figure 7 to give a comprehensive view of the incident duration saving with FSPs for dispatch policy B. An intuitive observation is that an incident that blocks two lanes has a greater effect on the traffic and it will take longer time for FSP to reach the incident scene, however this difference is not very large. To further illustrate the benefits of FSP program, savings of total vehicle hours of travel are presented in Figure 8 for dispatch policy B.
As shown in Figure 8, benefits of FSPs for incidents that block two lanes was much higher than incidents that block one lane. Since incidents blocking two-lanes have more severe
impacts on the traffic, FSPs can generate considerable more benefits on total delay. The incremental benefits of decreasing FSP average headway is not significant since decreasing FSP headway does not substantially decrease the incident duration. The average headway of 30 minutes demonstrates efficient use of FSP to respond to incidents.

CONCLUSIONS

This study evaluated the arrival of freeway service patrols (FSPs) at an incident scene using random assignment of FSPs and random spatial and temporal occurrence of incidents in a traffic simulation network using the Programmer module of the PARAMICS microscopic simulation model. The simulations were completed for two dispatch policies and different headways between FSP vehicles in the simulation network. The PARAMICS simulation model was found to be versatile for modeling these scenarios with the development of an Application Programming Interface (API). The developed incident generator simulated the occurrence of incidents in a stochastic fashion in terms of random assignments of locations and start time of incidents.

This research determined that increased deployment of FSPs in the highway network could substantially reduce incident durations by decreasing the average time to arrive at an incident scene. As headways between FSPs decreased, the arrival times of first-responding FSPs at the incident scene also decreased. This study also found incremental benefits of decreasing the headways by providing more FSP units in the network, which could be valuable information to decision makers seeking to deploy the optimum number of FSPs. The results also indicated that FSP operations provided increased benefits in terms of delay reductions with more number of lanes blocked due to an incident.

The study found that a policy allowing FSPs to deviate from their assigned patrol route was mostly beneficial with a small number of FSPs in the network. As the headway between FSPs in the network decreased, the effect of dispatch policies in reducing incident duration became insignificant. These finding will help decision makers decide policy choices related to the FSP assignments, service policies and levels of deployment.

This study did not evaluate the impacts of integrating other technologies and services with FSP in incident management. Further research should investigate the impacts of combining FSP services with other strategies, such as automatic incident detection, route diversion and ramp metering, in attaining additional benefits from multi-technology applications.

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