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BENEFITS OF HIGHWAY SERVICE PATROLS

H.E.L.P. PROGRAM EVALUATION:

BENEFIT/COST ANALYSIS

FINAL REPORT

June 5, 2008

University of Maryland, College Park

Benefits of Highway Service Patrols H.E.L.P. Program Evaluation: Benefit Evaluation

Prepared for
Hudson Valley Transportation Management Center and the I-95 Corridor Coalition

Prepared by
Center for Advanced Transportation technology
University of Maryland

Study Supervisor
Elise Miller-Hooks

Graduate Research Assistant
Jason (Chih-Sheng) Chou

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Executive Summary

Overview

Freeway service patrols (FSPs) are continuously roving vehicles whose purpose is to quickly respond to incidents and to provide necessary assistance to drivers of disabled vehicles or vehicles involved in a collision. FSPs operate along freeway segments. They also act as probe vehicles, providing real-time information on traffic conditions.

The goal of most FSP programs is to mitigate the impact of traffic incidents on traffic flow along these freeway segments. An FSP program, the Highway Emergency Local Patrol (H.E.L.P.) program, exists in the Lower Hudson Valley region of New York. This study evaluates the effectiveness of service patrol vehicles belonging to the H.E.L.P. program along a portion of the I-95 Corridor, which is composed of a segment of I-95 and several surrounding freeways.

Findings

This study determined that under very conservative assumptions concerning the monetary equivalent of travel delay and secondary incidents, the H.E.L.P program has led to the equivalent of $430,000 in annual savings on a 10-mile segment of I-287. These savings were estimated under the assumption that the H.E.L.P. program saved on average 20 minutes in incident duration. The savings which drove this $430,000 benefit include:

(a) 24,000 vehicle-hours in travel delay
(b) 2,900 gallons of fuel consumed
(c) 0.32 ton of hydrocarbon (HC)

(d) 3.6 ton of carbon monoxide (CO)
(e) 0.2 ton of nitrogen oxide (NO)
(f) 18 secondary accidents

Results of the study indicate that the program operates with a benefit-to-cost ratio of 2.68 assuming a cost of $40/truck-hour for operating the H.E.L.P. program or a 2.14 benefit-to-cost ratio assuming a cost of $50/truck-hour.

At an operating cost of $40/truck-hour, to break even, a comparable FSP program would require a minimum of eight minutes reduction in average incident duration (H.E.L.P. reduction is estimated to be 20 minutes) or 11 minutes at an operating cost of $50/truck-hour.

The H.E.L.P. program operates with better than two-to-one benefit-to-cost ratio under very conservative assumptions. It is entirely conceivable that its true benefit-to-cost ratio is significantly greater than two-to-one. Consequently, one can confidently assert that the H.E.L.P. program is justified and provides a sizable return on the public's investment.

Goal and Study Design

The primary goal of this study was to quantify the benefits of the H.E.L.P. program in terms of resulting reduction in congestion, secondary incidents, fuel consumption, and related environmental impacts of congestion. The study was conducted in two phases. In the first phase, statistical analyses designed to characterize spatial and temporal distributions, as well as service dispositions and call types, of traffic incidents arising during the study period of January 1, 2006 through June 30, 2006 over the study area (involving segments of I-287, I-684, the Taconic State Parkway and the Sprain Brook Parkway in the I-95 corridor) were conducted. Reduction in response times and resulting incident durations due to the execution of the H.E.L.P. program were estimated.

Significant savings in incident duration as a consequence of the H.E.L.P. program were noted. For example, average savings of approximately 20 minutes in incident duration for incidents involving a collision and 19 minutes for incidents involving a disabled vehicle were computed for the study area as a result of the presence of the H.E.L.P. program. Additional detail can be found in (Miller-Hooks and Chou, 2008).

In the second phase, the benefits of the H.E.L.P. program in terms of travel delay, fuel consumption, pollution causing emissions and secondary incidents were evaluated with the goal of assessing whether or not the program's benefits outweigh its costs.

This report describes the methodologies employed to estimate these benefits and describes the findings of the benefit-to-cost (B/C) analysis. A set of B/C ratios are provided for a range of average incident duration savings that might result from a comparable FSP program operating on a roadway with similar geometric characteristics to that considered in the study.

Techniques Used

A technique employing a microscopic traffic simulation platform was devised to estimate the savings in travel delay, fuel consumption and emissions. This technique replicated the incidents arising along a segment of I-287 that received assistance from the H.E.L.P. program during the study period. Another set of simulation runs were completed to estimate traffic characteristics given the same incident characteristics, but with an additional duration of between 5 and 25 minutes (in 5 minute-increments) to replicate scenarios where no response is received from the H.E.L.P. program. The benefits of the H.E.L.P. program can be quantified through analysis of the differences in the resulting simulated traffic characteristics.

To estimate the savings in terms of secondary incidents, the Simulation-Based Secondary Incident Filtering (SBSIF) method is proposed. This technique explicitly considers the dynamics of the temporal and spatial properties of traffic in estimating the incident impact area of a given incident. Any second incident falling within the impact area is identified as a secondary incident. For computational efficiency, a geometric-based technique involving the use of regression models for identifying the corner points of the impact area is developed for the SBSIF method. The method was applied to the incident database. Assuming a linear function of the secondary incidents with respect to total travel delay, an annual savings of at least 18 secondary incidents along the 10-mile stretch of I-287 could be attributed to the H.E.L.P. program.

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CHAPTER 1

Introduction

In the United States, it is estimated that nearly 60% of non-recurrent freeway congestion is caused by incidents (Lindley, 1987). This non-recurrent congestion negatively impacts safety and mobility. It induces enormous travel delay on travelers and results in secondary incidents, which cause approximately 18% of all freeway deaths according to (Brach, 2008). Moreover, traffic congestion results in the squandering of huge quantities of fuel and the emission of dangerous pollutants. To mitigate this impact due to incidents along freeways, Freeway Service Patrol (FSP) programs have been introduced nationwide. FSP programs supply continuously roving vehicles that traverse given beats. The drivers of these vehicles respond to incidents involving disabled vehicles, collisions, and debris to which they are dispatched or that they detect as they traverse their beats. Once arriving at an incident scene, the FSP vehicle driver can provide free services, such as changing a tire, supplying a small amount of gasoline, jump starting a battery, towing a vehicle out of the main lanes and off the freeway, or providing minor mechanical assistance. In the case of an accident requiring police or other emergency personnel presence, the FSP vehicle driver can call for help and can assist in redirecting traffic around the incident. Whether assisting with disabled vehicles or accidents, the goal of the FSP program is to mitigate the impact of the incident on upstream traffic. FSPs also act as probe vehicles, providing real-time information on traffic conditions.

FSP programs exist in New York State. This study considers the operations of such a program, referred to as the Highway Emergency Local Patrol (H.E.L.P.) program, that covers several regions within New York State. Additional detail concerning the program can be found in (Miller-Hooks and Chou, 2008). This study considers a portion of the H.E.L.P. program that runs service patrol vehicles along a portion of the I-95 Corridor in the Lower Hudson Valley region of New York.

In the first phase of this study, statistical analyses designed to characterize spatial and temporal distributions, as well as service dispositions and call types, of traffic incidents arising during the study period of January 1, 2006 though June 30, 2006 over the study area (involving segments of I-287, I-684, the Taconic State Parkway and the Sprain Brook Parkway in the I-95 corridor) were conducted. Reduction in response times and resulting incident durations due to the execution of the H.E.L.P. program were estimated. Significant savings in incident duration as a consequence of the H.E.L.P. program were noted. For example, average savings of approximately 20 minutes in incident duration for incidents involving a collision and 19 minutes for incidents involving a disabled vehicle were computed for the study area as a result of the presence of the H.E.L.P. program (Miller-Hooks and Chou, 2008). The primary goal of this second phase of the study is to estimate the benefits of the H.E.L.P. program in terms of travel delay, fuel consumption, emissions and secondary incidents, and to assess whether or not the program's benefits outweigh its costs. To estimate these benefits, a 10-mile segment (in both directions) of I-287 was modeled.

During the study period, 1,303 incidents arose along the study segment of I-287. 693 of these 1,303 incidents received service from the H.E.L.P. program during the H.E.L.P. hours of operations.

To evaluate the H.E.L.P. program in terms of savings in travel delay, fuel consumption, emissions and secondary incidents resulting from a reduction in incident duration as a consequence of the implementation of this program, the CORridor SIMulator (CORSIM) microscopic simulation software platform was employed. This simulation tool provided a means of evaluating the impact of the incidents on traffic, where such information could not be obtained through archived data. CORSIM was developed by the Federal Highway Administration (FHWA) in the 1970’s and has been repeatedly updated since. It is a discrete-time and stochastic based simulation platform designed specifically to model traffic operations. CORSIM estimates travel delay through travel time comparisons of traffic operating at free flow speeds as compared with speeds resulting from vehicle interactions that result from congestion. It also estimates fuel consumption by tracking the performance of individual simulated vehicle speed and acceleration rates. The estimation process relies on a standard fuel consumption rate table developed by Oak Ridge National Laboratory (Davis, 1999). This study employed a CORSIM simulation model developed for use in a prior study with similar purpose (Haghani and Ilescu, 2006). Haghani and Iliescu modeled a 10-mile segment of I-287 with three main lanes and a right-side shoulder. There are no on- or off-ramps in the model.

A technique employing the CORSIM traffic simulation platform with standard replication processes for simulating freeway incidents was devised to estimate the savings in travel delay, fuel consumption and emissions. This technique was used to replicate the incidents receiving response from the H.E.L.P. program given individual incident properties and prevailing traffic conditions. Another set of simulation runs were completed to estimate traffic characteristics given the same incident characteristics, but with an additional duration of between 5 and 25 minutes (in 5-minute increments) to replicate scenarios where no response was received from the H.E.L.P. program. Subsequently, analyses of the differences in the resulting simulated traffic characteristics were used to quantify benefits of the H.E.L.P. program. Details of the modeling approach and results from analysis of the H.E.L.P. program as operated in the segment are given in Chapter 2.

In Chapter 3, potential savings in terms of secondary incidents are estimated. To classify secondary incidents from the archived database, a Simulation-Based Secondary Incident Filtering (SBSIF) method is proposed and assessed with actual incident data after reviewing existing static- or dynamic-threshold secondary incident filtering techniques proposed in the literature. This technique explicitly considers the dynamics related to temporal and spatial properties of traffic in estimating the incident impact area of a given incident. Any second incident falling within the impact area is identified as a secondary incident. For computational efficiency, a geometric-based technique involving the use of regression models for identifying the corner points of the impact area was devised as a component of the SBSIF method. The SBSIF method employing visual inspection was applied to the incident database and 24 secondary incidents were identified to have resulted from the 693 incidents that received assistance from the H.E.L.P. program. Assuming a linear function of the secondary incidents with respect to total travel delay, savings in the number of secondary incidents due to the H.E.L.P. program were estimated.

In Chapter 4, the savings in terms of travel delay, fuel consumption, emissions and secondary incidents were converted into equivalent monetary values to obtain an estimate of the benefit-to-cost (B/C) ratio. A set of B/C ratios were provided for a range of average incident duration savings that might result from a comparable FSP program operating on a roadway with similar geometric characteristics to that considered in the study. The findings of this second phase of the study are provided in Chapter 5, along with suggestions for next steps that might be taken to generalize the proposed procedures and validate the assumptions employed in obtaining the study findings.

CHAPTER 2

Quantifying the Benefits of the H.E.L.P. Program

A first step in assessing the benefits of the H.E.L.P. program along the study segment of I-287 for the study period is to estimate the savings in travel delay that resulted from reduction in incident duration as a consequence of the program. To estimate such travel delay savings, the CORSIM microscopic simulation software platform is employed. If real-time traffic data had been collected just prior to and throughout the recovery period of each incident in the study period, actual travel delay could be estimated. Since such real-time data is not typically available, simulation is used to approximate actual conditions. In addition to estimating savings in travel delay, savings in fuel consumption and emissions are estimated. Emissions are estimated with the use of empirically derived equations that can be used to quantify levels of certain pollutants as a function of travel delay.

In Section 2.1, the CORSIM simulation model for the study segment of I-287 and methods employed for replicating incidents and modeling the traffic response are described. An illustrative example involving an incident arising along the shoulder is given to show how the model replicates the impact of the incident on traffic flow. Estimates of savings in travel delay, fuel consumption and emissions resulting from the presence of the H.E.L.P. program for the study period and study location are provided in Section 2.2.

2.1 Simulation Test Bed and Modeling Techniques

The CORSIM simulation software is a commonly used microscopic traffic simulation software package that is often employed in evaluating traffic operations along a roadway segment or a network of roadways. The model adopts car-following and lane-changing behavior models to mimic traffic flow and quantifies related measures of effectiveness, such as travel delay, speed, occupancy and volume. The car-following model defines the interaction between leading and lagging vehicles by setting gap distance, vehicle speed, and speed difference between each pair of cars that are within close proximity to one another. The lane-changing model seeks to simulate weaving and merging maneuvers through consideration of acceptable gap distances.

As is the case with most simulation tools, behavior that cannot be predicted with certainty is replicated from random variates employed to model stochasticity in the behavior. For example, the gap distance required for a driver to decide to change lanes will vary from driver to driver and vehicle operational characteristics will vary from vehicle to vehicle. In each run of the simulation, a series of randomly selected events will arise through instantiations of each random variate. If a new seed is used to start the course of each series of random numbers that are employed in the selection of each instantiation, then a new stream of events will arise. The greater the number of replications, the more realistic the average behavior. Thus, multiple replications must be conducted. The greater the number of replications, however, the greater the computational effort required. Haghani and Iliescu (2006) recommend that at least five runs be conducted in a similar context.

Through prior efforts, a CORSIM simulation model was developed for the I-287 study segment (Haghani and Iliescu, 2006) that was employed in the efforts described in this chapter. All parameter settings required for calibrating the simulation model were set as in the prior model specifications (as listed in Table 2.1).

Table 2.1 Parameters for CORSIM model of I-287 study segment

Parameter	value
Multiplier for desire to make a discretionary lane change	0.1 [0 to 1]
Advantage threshold for discretionary lane change	0.9 [0 to 1]
Time to complete a lane change maneuver	2 sec
Gap Acceptance Parameter	3
Free flow speed	65 mph
Car following sensitivity factor	0.35 to 1.25
Pitt car following constant	3 feet
Average vehicle length	14 feet
Minimum separation for generation of vehicles	1 sec
Leader's maximum deceleration preceived by the follower	15 feet/sec
Headway distribution	uniform

As the CORSIM simulation model is run and traffic conditions are replicated, a set of traffic measures, including incident properties (incident onset and duration, location, capacity reduction and lanes impacted as a consequence of the rubberneck effect, warning sign location (e.g. a flare), and lane closure status) are recorded. To analyze the impact of an incident, four stages are considered, as portrayed in Figure 2.1. In the first stage, prior to the incident, traffic flow is assumed to be stable. At the onset of the incident (stage 2), shoulder and/or freeway lanes may become blocked and capacity along these lanes is nearly instantaneously impacted. In stage 3, it is assumed that a warning sign is set up for warning the upstream traffic (or that the upstream traffic can discern that an incident has arisen a short distance prior to coming into contact with the incident). Drivers passing by the incident scene may reduce their speed to observe the incident, creating the so-called rubbernecking phenomenon. Upon clearance of the incident, normal traffic flow conditions are re-established.

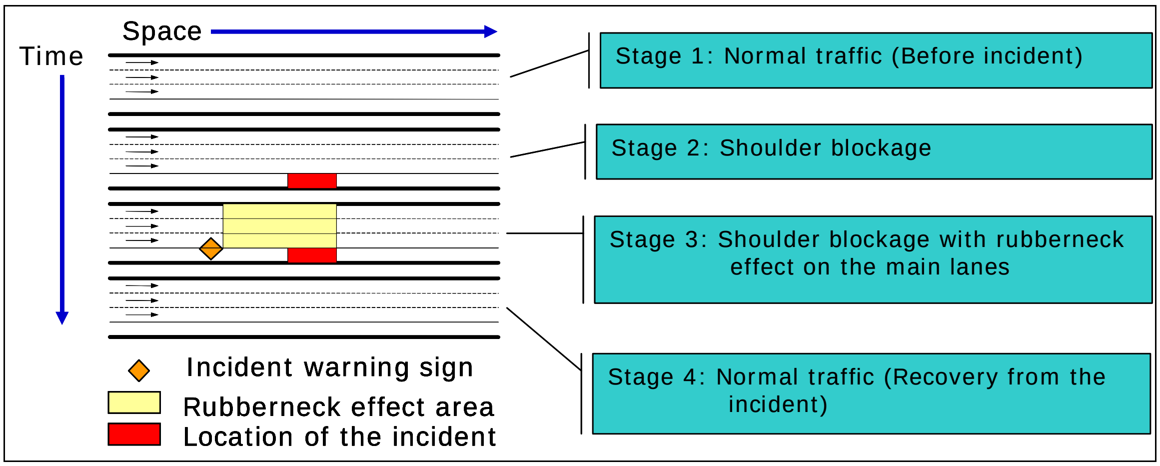

Figure 2.1 Procedures for modeling an incident

Details of specific components of this four-stage incident modeling approach are presented in the following subsections.

2.1.1 Concepts for the Experimental Design

During the study period, H.E.L.P. vehicles responded to 693 incidents that arose during H.E.L.P. hours of operation along the study segment of I-287. To estimate savings in travel delay and fuel consumption that resulted as a consequence of this program through the program's impact on incident duration, a set of simulation runs were designed. Incident durations reported in the data archives are due to the existence of the H.E.L.P. program. The impact on traffic under similar circumstances assuming that such a program did not exist, where incident durations would be longer, must be compared to the impact under existing conditions. Thus, actual incident durations replicated directly from the incident data represent the “base case,” where it is assumed that the H.E.L.P. program existed. To estimate the savings that were achieved as a consequence of this program, replications were run where incident durations were lengthened by between 5 and 25 minutes (in 5- minute increments). These replications are meant to model circumstances assuming that such a program were nonexistent. Thus, for example, an incident with 10-minute duration that arose during the study period would be modeled with 10-minute duration in the base case, but with 15-, 20-, 25-, 30-, and 35-minute durations in additional runs. Such additional time is based on average savings expected from such a program. The addition of 5 minutes, thus, is employed to estimate the additional travel delay and fuel consumption that would have been incurred had a FSP program with average incident duration savings of 5 minutes not been in place. Thus, the difference in performance measurements between the base case and each extended case provides the savings in such performance metrics that are estimated to have resulted from the FSP program.

For each incident, traffic is modeled from a period of time just prior to the incident through at least 30 minutes (longer for longer incident durations) past the time of incident resolution.

2.1.2 Capacity Reduction and Rubberneck Effect Setting

When a freeway incident occurs, roadway capacity is reduced and non-recurrent delay is induced. The level of change in these quantities depends on the incident properties. The estimated capacity reduction under varying lane blockage status is shown in Table 2.2 (Highway Capacity Manual, 2000). For example, if an incident blocking one lane along a three lane freeway segment arises, it is estimated that the remaining capacity will be only 49% of its uninhibited value. To achieve the desired capacity reduction, a rubberneck effect parameter within the CORSIM simulation model can be set. This parameter affects the acceptable gap between leading and lagging vehicles.

Table 2.2 Percentage of available freeway capacity

Number of lanes	Shoulder (disabled vehicle)	Shoulder (collision)	1 lane blocked	2 lanes blocked	3 lanes blocked
2	0.95	0.81	0.35	0.00	N/A
3	0.99	0.83	0.49	0.17	0.00
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.40	0.20
6	0.99	0.89	0.71	0.50	0.25
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	0.63	0.41

Source: Highway Capacity Manual (2000)

Within the CORSIM software manual (CORSIM User Manual, 1999), a technique is supplied for setting the rubberneck effect parameter to achieve varying levels of capacity reduction for given roadway geometries. Within this technique, the contribution of each lane to overall capacity reduction is computed as a function of a chosen rubberneck effect parameter value. The capacity reduction is directly proportional to the remaining capacity of each lane, which is determined through the rubberneck effect parameter setting. This technique of setting the rubberneck effect parameter to achieve a known level of capacity reduction as determined through the HCM was employed within this work.

From Table 2.2 and the rubberneck effect parameter setting technique, appropriate rubberneck effect parameter values were estimated for incidents with varying numbers of lanes blocked for a three-lane freeway segment. The results are given in Table 2.3.

Table 2.3 Computed rubberneck effect value for different lane blockage scenarios

	Lane blockage scenario on a 3-lanes freeway segment				
	Shoulder blocked (disabled vehicle)	Shoulder blocked (collision)	1 lane blocked	2 lanes blocked	3 lanes blocked
Residual capacity	99%	83%	49%	17%	N/A
Capacity reduction	1%	17%	51%	83%	N/A
REP(%)	**1**	**17**	**26**	**49**	N/A
Computed reduction	1%	17%	50.67%	83%	N/A

Note: Residual capacity values are adopted from Table 2.2
Rubberneck Effect Parameter (REP) percentage is calculated through the capacity reduction equation given in the CORSIM user manual

To illustrate how this table can be employed in the setting of the rubberneck effect parameter for the three-lane study segment, assume that one lane has been blocked by an incident. The rubberneck effect parameter should be set to 26% to yield a 51% reduction in capacity. Note that different parameter settings are given for incidents involving disabled vehicles as opposed to a collision for the case that only the shoulder is blocked.

Once an incident occurs, it is assumed that a warning sign is set up to warn the upstream traffic of the incident. Since guidelines suggest that the optimal location for such a warning sign is 500 feet behind the incident along a highway (Guidelines for Emergency Traffic Control, 2006), a distance of 500 feet was set for the warning sign in this study. Note that this provides the driver with approximately five seconds between passing the warning sign and passing the incident scene assuming a speed of 65 miles per hour. In the CORSIM model, the rubberneck effect parameter is applied to the stretch of roadway between the warning sign and the incident scene.

2.1.3 Estimating Prevailing Traffic Conditions

The impact of any particular incident will depend on prevailing traffic conditions at the time of the incident. It is, therefore, desirable to have knowledge of such prevailing conditions when studying savings in incident impact resulting from the existence of the H.E.L.P. program. Since the necessary traffic volume data did not become available in the study area until after the study period, traffic volume data for the study roadway segment was employed for the same period, but in the following year. Specifically, reports from six detectors (three in each direction) along I-287 were made available through Transcom. Details associated with the detector locations and dates available for analysis are listed in Appendix A.

Average weekday and weekend hourly traffic volumes by month were computed from the available data. Figure 2.2 shows how this average volume data along I-287 varied over the day between January and June of 2007 for a set of locations in the study area.

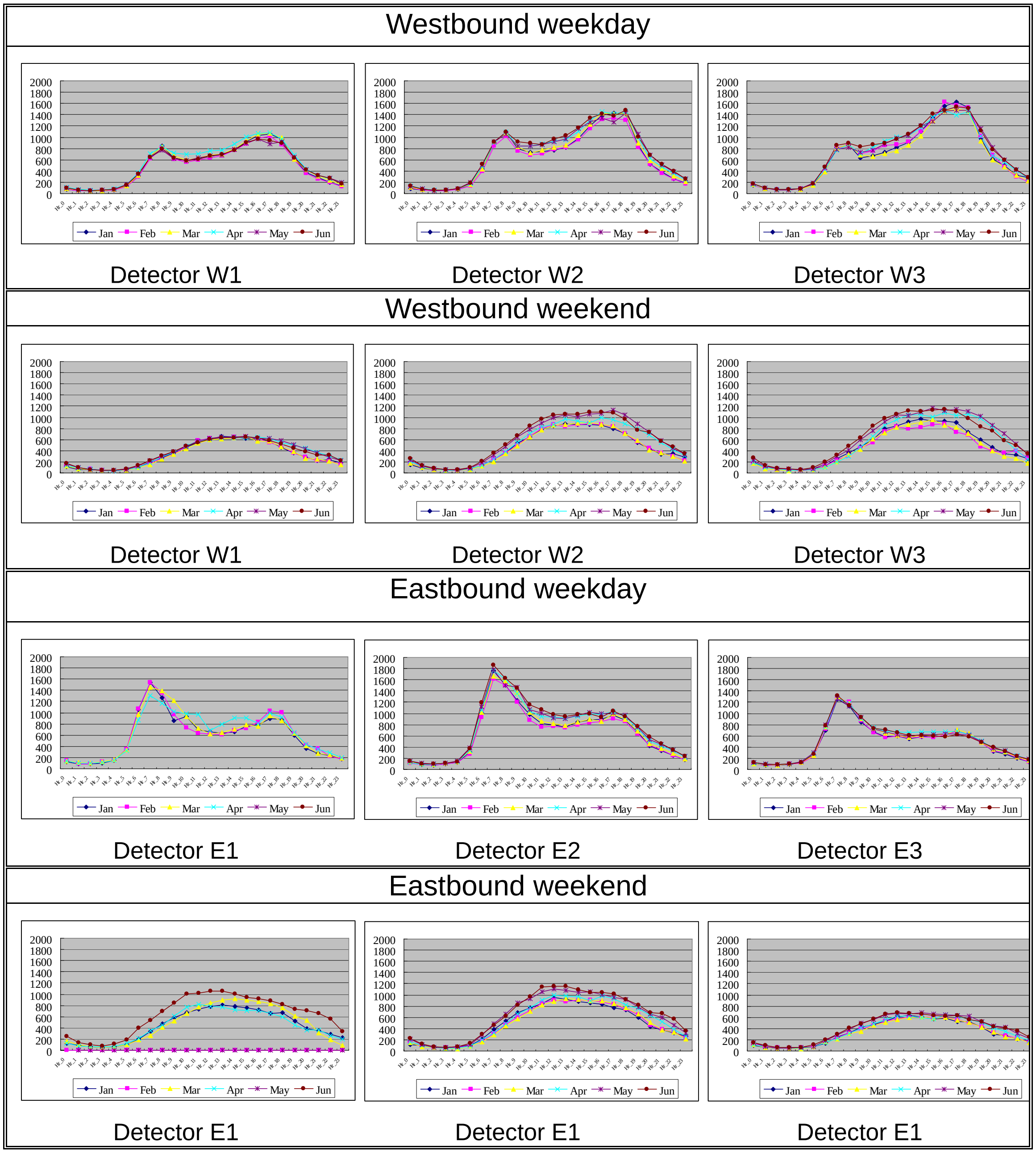

Figure 2.2 Time of day dynamics in traffic volume along I-287 for varying locations

The average weekday hourly volume data by month for 2007 was employed in the simulation runs. For a given incident, the average hourly volumes determined at the nearest detector for the time period in which the incident impacted traffic was employed.

2.1.4 Generating Scenarios for the Simulation Runs

693 incidents arising in the study roadway segment and study period that received assistance from the H.E.L.P. program were simulated within the CORSIM platform using the incident properties and estimates of likely prevailing traffic conditions as discussed in Section 2.1.3. The simulation time for each run was set as a function of the incident duration. The incidents with duration less than 90 minutes were simulated for two hours, while the incidents with duration of more than 90 minutes (only nine such incidents arose during the study period) were simulated for three hours. The excess time beyond the incident duration was required to ensure that prevailing traffic conditions could be reestablished before concluding the run.

For the base case runs, the incident duration was set as indicated in the data archives. An additional five sets of runs were made assuming the incident duration is extended by 5 through 25 minutes, in 5-minute increments, to represent circumstances in which the H.E.L.P. program is not available; that is, it is assumed that the H.E.L.P. program (or a comparable program) saves between 5 and 25 minutes on average in incident duration. This experimental design is described in Section 2.1.1.

As CORSIM only allows 9,999 seconds for each incident, back-to-back incidents were established to model incidents of greater duration. Each incident scenario was replicated five times using different random seeds and the average performance metrics were obtained over the five runs. This ensures that if circumstances that are randomly chosen in a given replication are significantly different from ordinary that they contribute to, but do not dominate, the final measurements. A total of 20,790 replications were conducted, requiring more than

41,580 simulation hours. Pseudo-code for the methodology employed in completing these simulation runs is given in Appendix B.

2.1.5 Illustrating Traffic Impact of Incident in Simulation Platform

Results of the statistical analyses reported in (Miller-Hooks and Chou, 2008) indicate that the H.E.L.P. program personnel assisted more than 86% of the disabled vehicle incidents during the H.E.L.P. hours along I-287. In 91% of these incidents, the H.E.L.P. vehicle driver blocked only the shoulder in his/her effort to provide service. In this section, this most typical scenario involving an incident blocking the shoulder is depicted to illustrate the incident impact on traffic as identified within the simulation platform. The incident duration is assumed to be 10 minutes. Figure 2.3 shows the progression of events as provided through the animation capabilities of the simulation tool.

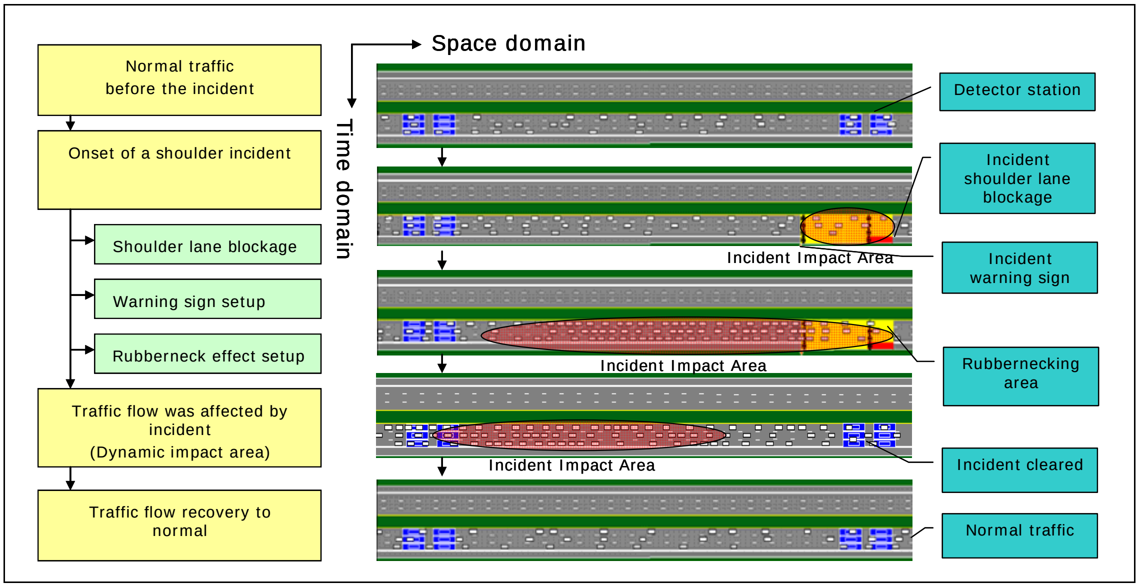

Figure 2.3 Process and animation for simulating a shoulder blockage incident

One can observe in the figure free flow traffic prior to the onset of the incident. Only those vehicles in the direct vicinity of the incident are initially impacted by the incident. As these closest vehicles reduce their speeds in response to the incident, queues build up forming shockwaves and the incident impact area grows. Once the incident is cleared, vehicles at the front of the impact area increase their speeds, a recovery shockwave forms and prevailing traffic conditions return.

To assess the impact of the assumed 10-minute incident duration on traffic flow characteristics, a number of simulation runs were conducted over varying prevailing traffic volume levels, i.e. between 400 and 2,300 vehicles per lane per hour in increments of 100 vehicles per lane per hour. Figure 2.5 shows the results in terms of volume, speed and occupancy reported by the upstream detector (employed within the simulation model to obtain information on the simulated traffic) of the incident scene. It can be observed that when the demand volume is greater than 1,500 vehicles per lane per hour, the incident has obvious impact on system performance. In contrast, the impact from the incident in terms of traffic flow characteristics is negligible when the traffic volume is less than 1,500 vehicles per lane per hour. This finding is consistent with results from an earlier study (Haghani and Iliescu, 2006).

Figure 2.4 also shows that the performance measurement of speed is a good indicator of traffic impact. That is, when the incident occurs, speeds decrease and when the incident is cleared and traffic has recovered, speeds return to their pre-incident levels. One might also consider using traffic volume or occupancy to discern the incident's onset or conclusion; however, speed offers less variability as a function of hourly traffic volume. This insight is employed in Chapter 3 in identifying the impact area of an incident for use in classifying incidents as secondary.

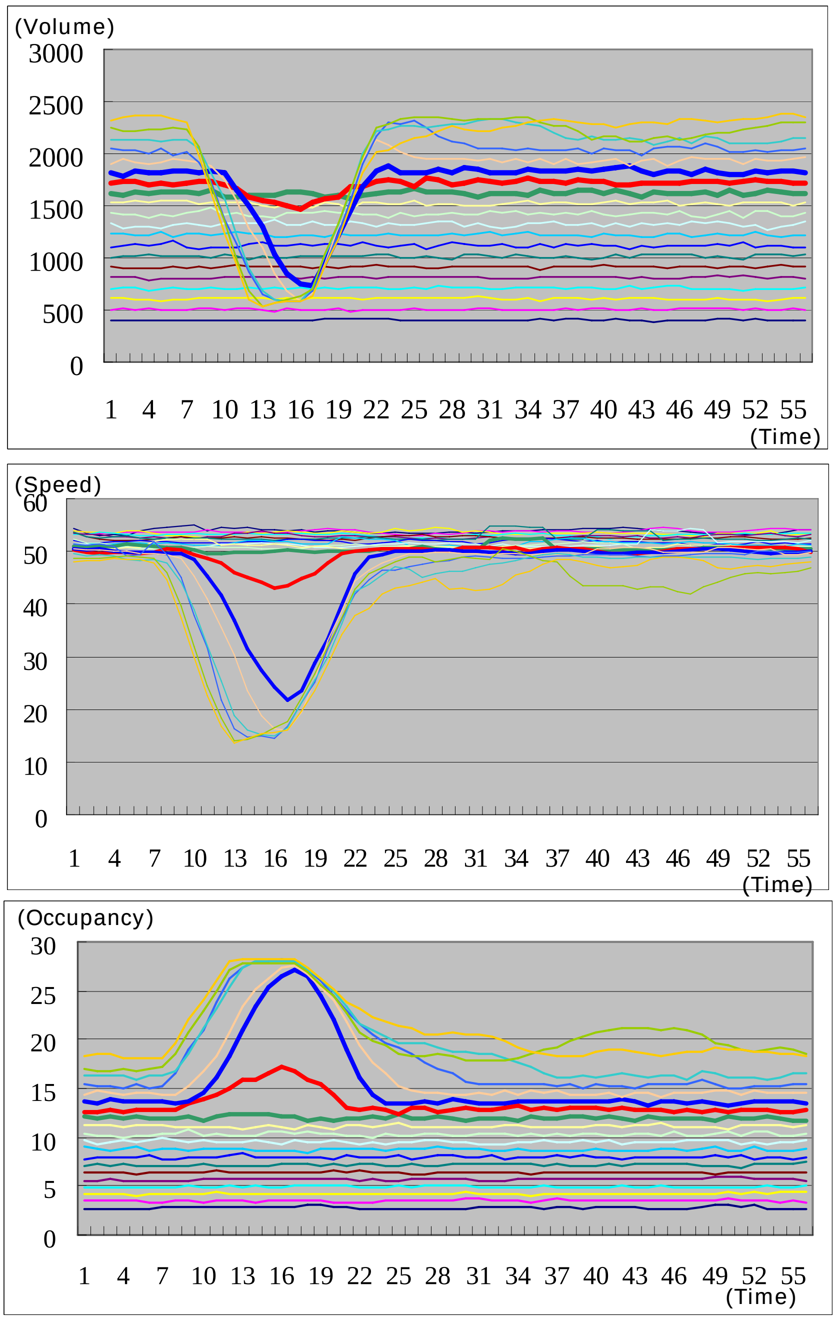

Figure 2.4 Profiles of incident impact on traffic flow characteristics

2.2 Estimating Benefits of the H.E.L.P. Program

Once the rubberneck effect parameters were set, traffic volumes were estimated, and the set of simulation runs were designed, the 693 incidents that arose were replicated. Note that the impact on traffic in the opposite direction was not considered. Five runs of each of the 693 incidents were conducted and the results were aggregated into 12 categories as a function of traffic volume (between 0 and 2,000 vehicles per lane per hour in increments of 500 vehicles per lane per hour) and lane closure (shoulder, one-lane blocked or two-lanes blocked). For each group, the total savings in terms of performance measures of travel delay and fuel consumption were computed. Savings were estimated based on the difference between the performance measure as measured on the base case and each incident duration extended case: For

i : Incident i,

j : 12 categories classified by volume and lane blockage properties,

k : Five incident duration extension cases, $k = (5, 10, 15, 20, 25)$,

$pm_i^{e,k}$: Average performance measure of incident i with k-minute incident duration extension, and

pm_i^b : Average performance measure of incident i with actual incident duration as in the base case,

$$\sum_{i \in j} (pm_i^{e,k} - pm_i^b)_j \qquad (2.1).$$

Table 2.4 shows the results of total savings in travel delay (in vehicle-hours) for each of the 12 categories. These savings are computed by first averaging over the set of five runs under each incident and then taking the sum of differences between these averages for the base and extended case pairs. For example, there were 31 H.E.L.P. incidents under the category of one lane-blocked and volume level of 1,000 to 1,500 vehicles per lane per hour. For this category, the total savings in travel delay was computed to be 1026.35 vehicle-hours assuming that the H.E.L.P. program saved 5 minutes in average incident duration (i.e. as compared with the five-minute extended case). Thus, an average of 33.11 vehicle-hours savings in travel delay per incident was estimated, inferring that the H.E.L.P. program would save approximately 33 vehicle-hours in travel delay under similar prevailing traffic conditions for the given 5-minute incident duration savings. Savings in travel delay is most notable at higher traffic volumes and where one or more travel lanes are blocked, as one would expect.

Table 2.5 provides results of the simulation runs in terms of savings in fuel consumption (in gallons). The same categories and computational approach (equation 2.1) as employed in estimating savings in total and average travel delay are employed. For example, assume a five-minute incident duration reduction is estimated for the H.E.L.P. program. Then, the 31 incidents categorized under one lane-blocked and volume level between 1,000 and 1,500 vehicles per lane per hour contributed to a total savings of 128.51 gallons of fuel consumed, or an average savings in fuel consumption for each incident of 4.15 gallons. The greater the traffic volume, incident duration and savings due to the program, the great the savings in fuel consumption.

Once savings in travel delay are estimated, rough estimates of savings in pollution causing emissions, specifically in hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxide (NO), can be estimated using the following factors: 13.073, 146.831, and 6.261 grams per hour delay, respectively (CHART, 2006). By using these rates multiplied by the total delay savings found in Table 2.4, the savings in terms of emissions for different incident duration extension cases can be estimated as shown in Tables 2.6 through 2.8.

Recall that the average incident duration savings for incidents involving both disabled vehicles and collisions due to the H.E.L.P. program was found to be approximately 20 minutes. As shown in Tables 2.4 through 2.8, over the six month study period for the I-287 study roadway segment, more than 12,182 vehicle hours of travel delay, 1,451 gallons of fuel consumed, 0.16 ton of HC, 1.8 tons of CO and 0.1 ton of NO were saved due to the operation of the H.E.L.P. program.

2.3 Conclusions

During the study period, the H.E.L.P. program assisted 693 incidents along the study segment of I-287 and saved an average of 19 and 20 minutes in incident duration for incidents involving either disabled vehicles and collisions, respectively (Miller-Hooks and Chou, 2008). To quantify the benefits of such savings in incident duration, in this chapter savings in terms of travel delay, fuel consumption and emission pollutions resulting from the reduction in incident duration were estimated. The CORSIM simulation platform was employed for this purpose. Procedures for replicating the 693 incidents with their individual properties and prevailing traffic conditions were presented. An illustrative example was discussed and it was noted that significant savings in terms of travel delay, fuel consumption and emissions for an incident involving shoulder blockage would result only if traffic volumes were at least 1,500 vehicles per lane per hour. It was estimated that 12,182 vehicle hours of travel delay, 1,451 gallons of fuel, 0.16 ton of HC, 1.8 tons of CO and 0.1 ton of NO were saved during the six-month study period for the I-287 study roadway segment along which the H.E.L.P. program operates.

Table 2.4 Savings in travel delay (vehicle-hours)

Travel Delay (vehicle hours)			5 minutes reduction		10 minutes reduction		15 minutes reduction		20 minutes reduction		25 minutes reduction	
	Volume	Freq.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.
Shoulder	< 500	37	1.06	0.03	0.64	0.02	1.13	0.03	0.87	0.02	0.63	0.02
	500-1000	312	23.54	0.08	24.00	0.08	25.11	0.08	26.98	0.09	30.97	0.10
	1000-1500	221	63.23	0.29	78.20	0.35	87.84	0.40	97.11	0.44	121.89	0.55
	>1500	30	180.29	6.01	391.28	13.04	631.53	21.05	889.75	29.66	1,168.63	38.95
One Lane	< 500	7	0.18	0.03	0.61	0.09	0.55	0.08	0.69	0.10	0.41	0.06
	500-1000	45	12.30	0.27	22.74	0.51	36.08	0.80	50.90	1.13	66.60	1.48
	1000-1500	31	1,026.35	33.11	2,254.95	72.74	3,684.56	118.86	5,330.75	171.96	7,459.18	240.62
	>1500	4	557.75	139.44	1,194.70	298.68	1,854.17	463.54	2,558.43	639.61	3,496.60	874.15
Two Lanes	< 500	0	0	-	0	-	0	-	0	-	0	-
	500-1000	5	508.54	101.71	1,048.93	209.79	1,650.09	330.02	2,293.78	458.76	3,252.08	650.42
	1000-1500	1	184.69	184.69	412.76	412.76	661.48	661.48	933.22	933.22	1,207.25	1,207.25
	>1500	0	0	-	0	-	0	-	0	-	0	-
Total		693	2,557.93		5,428.81		8,632.54		12,182.48		16,804.24	

Table 2.5 Savings in fuel consumption (gallons)

Fuel Consumption (gallons)			5 minutes reduction		10 minutes reduction		15 minutes reduction		20 minutes reduction		25 minutes reduction	
	Volume	Freq.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.
Shoulder	< 500	37	2.35	0.06	4.79	0.13	4.66	0.12	4.19	0.11	2.24	0.06
	500-1000	312	38.49	0.12	39.00	0.12	51.34	0.16	51.18	0.16	58.66	0.19
	1000-1500	221	57.99	0.26	66.93	0.30	74.33	0.34	88.96	0.40	106.35	0.48
	>1500	30	36.86	1.23	73.02	2.43	119.64	3.99	161.24	5.37	209.22	6.97
One Lane	< 500	7	0.20	0.03	0.45	0.06	0.37	0.05	0.26	0.04	0.59	0.08
	500-1000	45	8.51	0.19	14.54	0.32	21.69	0.48	27.75	0.62	35.85	0.80
	1000-1500	31	128.51	4.15	271.42	8.76	435.60	14.05	627.21	20.23	780.57	25.18
	>1500	4	69.14	17.28	144.97	36.24	199.78	49.95	244.12	61.03	292.14	73.04
Two Lanes	< 500	0	0	-	0	-	0	-	0	-	0	-
	500-1000	5	37.51	7.50	74.74	14.95	119.25	23.85	161.31	32.26	171.39	34.28
	1000-1500	1	19.28	19.28	42.65	42.65	63.83	63.83	84.83	84.83	103.74	103.74
	>1500	0	0	-	0	-	0	-	0	-	0	-
Total		693	398.84		732.51		1,090.49		1,451.05		1,760.75	

Table 2.6 Savings in HC (grams)

Emission - HC (grams)			5 minutes reduction		10 minutes reduction		15 minutes reduction		20 minutes reduction		25 minutes reduction	
	Volume	Freq.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.
Shoulder	< 500	37	13.81	0.36	8.31	0.22	14.72	0.39	11.35	0.30	8.24	0.22
	500-1000	312	307.76	0.99	313.75	1.01	328.24	1.05	352.66	1.13	404.82	1.30
	1000-1500	221	826.55	3.74	1,022.33	4.63	1,148.33	5.20	1,269.47	5.74	1,593.44	7.21
	>1500	30	2,356.88	78.56	5,115.18	170.51	8,256.02	275.20	11,631.65	387.72	15,277.50	509.25
One Lane	< 500	7	2.33	0.33	7.92	1.13	7.24	1.03	9.05	1.29	5.41	0.77
	500-1000	45	160.77	3.57	297.28	6.61	471.67	10.48	665.36	14.79	870.69	19.35
	1000-1500	31	13,417.47	432.82	29,478.96	950.93	48,168.31	1,553.82	69,688.92	2,248.03	97,513.86	3,145.61
	>1500	4	7,291.47	1,822.87	15,618.37	3,904.59	24,239.62	6,059.90	33,446.38	8,361.60	45,711.03	11,427.76
Two Lanes	< 500	0	0	-	0	-	0	-	0	-	0	-
	500-1000	5	6,648.14	1,329.63	13,712.61	2,742.52	21,571.57	4,314.31	29,986.64	5,997.33	42,514.44	8,502.89
	1000-1500	1	2,414.48	2,414.48	5,396.06	5,396.06	8,647.55	8,647.55	12,199.93	12,199.93	15,782.43	15,782.43
	>1500	0	0	-	0	-	0	-	0	-	0	-
Total			33,439.66		70,970.77		112,853.27		159,261.41		219,681.86	

Table 2.7 Savings in CO (grams)

Emission - CO (grams)			5 minutes reduction		10 minutes reduction		15 minutes reduction		20 minutes reduction		25 minutes reduction	
	Volume	Freq.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.
Shoulder	< 500	37	155.05	4.08	93.38	2.46	165.33	4.35	127.45	3.35	92.50	2.43
	500-1000	312	3,456.70	11.08	3,523.94	11.29	3,686.63	11.82	3,960.91	12.70	4,546.77	14.57
	1000-1500	221	9,283.54	42.01	11,482.48	51.96	12,897.64	58.36	14,258.17	64.52	17,896.94	80.98
	>1500	30	26,471.57	882.39	57,451.74	1,915.06	92,728.48	3,090.95	130,642.29	4,354.74	171,591.11	5,719.70
One Lane	< 500	7	26.14	3.73	88.98	12.71	81.34	11.62	101.61	14.52	60.79	8.68
	500-1000	45	1,805.73	40.13	3,338.94	74.20	5,297.66	117.73	7,473.11	166.07	9,779.24	217.32
	1000-1500	31	150,700.00	4,861.29	331,096.56	10,680.53	541,008.22	17,451.88	782,719.65	25,249.02	1,095,238.86	35,330.29
	>1500	4	81,894.99	20,473.75	175,419.58	43,854.90	272,250.22	68,062.56	375,657.13	93,914.28	513,408.98	128,352.25
Two Lanes	< 500	0	0	-	0	-	0	-	0	-	0	-
	500-1000	5	74,669.44	14,933.89	154,014.85	30,802.97	242,283.78	48,456.76	336,798.60	67,359.72	477,506.16	95,501.23
	1000-1500	1	27,118.51	27,118.51	60,606.55	60,606.55	97,126.06	97,126.06	137,025.04	137,025.04	177,262.31	177,262.31
	>1500	0	0	-	0	-	0	-	0	-	0	-
Total			375,581.67		797,117.00		1,267,525.36		1,788,763.96		2,467,383.66	

Table 2.8 Savings in NO (grams)

Emission - NO (grams)			5 minutes reduction		10 minutes reduction		15 minutes reduction		20 minutes reduction		25 minutes reduction	
	Volume	Freq.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.
Shoulder	< 500	37	6.61	0.17	3.98	0.10	7.05	0.19	5.43	0.14	3.94	0.10
	500-1000	312	147.40	0.47	150.26	0.48	157.20	0.50	168.90	0.54	193.88	0.62
	1000-1500	221	395.86	1.79	489.62	2.22	549.97	2.49	607.98	2.75	763.14	3.45
	>1500	30	1,128.77	37.63	2,449.79	81.66	3,954.02	131.80	5,570.70	185.69	7,316.79	243.89
One Lane	< 500	7	1.11	0.16	3.79	0.54	3.47	0.50	4.33	0.62	2.59	0.37
	500-1000	45	77.00	1.71	142.38	3.16	225.90	5.02	318.66	7.08	417.00	9.27
	1000-1500	31	6,425.98	207.29	14,118.24	455.43	23,069.06	744.16	33,375.84	1,076.64	46,701.93	1,506.51
	>1500	4	3,492.07	873.02	7,480.04	1,870.01	11,608.98	2,902.25	16,018.34	4,004.59	21,892.20	5,473.05
Two Lanes	< 500	0	0	-	0	-	0	-	0	-	0	-
	500-1000	5	3,183.97	636.79	6,567.33	1,313.47	10,331.19	2,066.24	14,361.38	2,872.28	20,361.27	4,072.25
	1000-1500	1	1,156.36	1,156.36	2,584.32	2,584.32	4,141.54	4,141.54	5,842.87	5,842.87	7,558.62	7,558.62
	>1500	0	0	-	0	-	0	-	0	-	0	-
Total			16,015.13		33,989.75		54,048.38		76,274.43		105,211.36	

CHAPTER 3

Secondary Incident Analysis

Traffic incidents are a major source of non-recurrent congestion on the United States' freeways. Such incidents negatively impact the safety and mobility of our freeways through reduced roadway capacity, increased travel delay and increased likelihood of secondary incidents (i.e. collisions that occur as a consequence of changes in traffic flow conditions resulting from a primary incident). The likelihood of the occurrence of secondary incidents can be reduced by reducing the incident impact on traffic flow through prompt response to the primary incident. FSP programs that respond quickly to incidents as they arise can be an effective tool in preventing the occurrence of secondary incidents.

In Section 3.1, methods from the literature for filtering historical traffic data to identify and classify incidents as secondary incidents are reviewed. The majority of works propose static filtering threshold methods that can often misclassify incidents as secondary. Several works propose dynamic threshold methods that overcome some of the shortcomings of such static threshold techniques; however, these techniques have significant deficiencies and, additionally, require significant computational effort. In Section 3.2, a geometric-based method for data filtering and classification for this purpose that overcomes the drawbacks of existing filtering methods is proposed. In Section 3.3, the proposed methodology is applied to the incident and traffic data from the study segment of I-287 during the study period . Twenty-seven secondary incidents were identified with the use of this technique. An estimation of the reduction in secondary incidents as a result of the H.E.L.P. program is discussed in Section 3.4. Conclusions follow in Section 3.5.

3.1 Review of Secondary Incident Filtering Methods

Numerous methods have been proposed for identifying secondary incidents. One approach to classify incidents as secondary could be to entrust this categorization to police officers or other personnel who record information about incidents to which they respond or employees of traffic management centers, where observations via CCTV monitoring can be employed. Such methods would, however, require human judgment and wide visual perspective.

Numerous automated approaches to identifying whether or not an incident is secondary to another incident via computer programs that filter data in archived incident databases have been proposed in the literature. The majority of these approaches employ temporal and spatial thresholds related to the primary incidents. For example, Ruab (1997) used static thresholds of 1,600 meters and 15 minutes. Any incident arising within 15 minutes of resolution of another incident and within one mile of that incident is defined as a secondary incident. Other works that employ similar static thresholds include: Moore et al (2004), Hirunyanitiwattana and Mattingly (2006) and Zhan et al (2007).

Chilukuri and Sun (2006) proposed the use of a progression curve for identifying secondary incidents involving a spatial threshold that is a nonlinear function of time beginning after the occurrence of a primary incident. The progression curve is constructed from affected distance lengths (defined as the distance from the location of an incident to the back of the developing queue) computed from archived incident data. Incidents are classified as secondary incidents if they fall under the curve. A simulation-based approach for identifying the space-time incident impact area of individual incidents was introduced by Haghani and Iliescu (2006). In their approach, the incident impact area is identified from the shockwave that arises as a consequence of the incident in the simulation model. A set of preselected time intervals, along with occupancy data employed to evaluate queue lengths, are employed in seeking the impact area during a specific time interval for each incident. In each iteration of the procedure, the time-dimension is increased by a constant interval employed in impact area identification. The procedure is repeated until the occupancy data indicates that traffic has returned to pre-incident conditions. Any incident arising in the impact areas identified for each time interval up to the last time interval tested is considered to be a secondary incident.

Table 3.1 Summaries of the filtering methods proposed in the literature

Author, Year	Method
Raub, 1997	Static method with thresholds of 1,600 meters and 15 minutes from incident resolution
Moore et al, 2004	Static method with filter algorithm using thresholds of two miles and two hours from incident identification
Chilukuri and Sun, 2006	Dynamic method employing progression curves over space and time based on incident queue length information
Hirunyanitiwattana and Mattingly, 2006	Static method with thresholds of two miles and 60 minutes from incident identification
Haghani and Iliescu, 2006	Dynamic, simulation-based method employing shockwaves
Zhan et al, 2007	Static method with thresholds of two miles and 15 minutes from incident resolution

In all of these prior works, it is assumed that the incidents occurring within a defined time period and spatial area are secondary incidents. However, there is no agreement on the threshold values to be employed in defining this timeframe and spatial area. Moreover, the static threshold-based approaches do not provide scientific-based justification for the threshold values that they employ. These methods, therefore, can lead to misclassification errors, i.e. mistakenly identifying or not identifying an incident as secondary to another. The progression curves proposed by Chilukuri and Sun (2006) compensate for the inadequacies of the static based approaches by establishing thresholds based on queueing information associated with primary incidents. This approach assumes that queueing information can be gathered from the archived incident database; however, it is often the case that limited queuing information, at best, can be retrieved from such records. Additionally, this method applies an identical function (in the form of a progression curve) over all incidents, regardless of the number of lanes blocked or traffic volume, for identifying secondary incidents. The simulation method of Haghani and Iliescu (2006) considers the dynamics associated with traffic in the aftermath of an incident. Their approach seeks to estimate the impact area through simulation. The impact area is mathematically represented by rectangles with a dimension in time. The smaller the time interval considered, the greater the accuracy of the estimation method, but the smaller the time interval, the greater the computational effort required to identify secondary incidents from within the archived data.

In this chapter, a computationally efficient simulation-based secondary incident filtering method, the Simulation-Based Secondary Incident Filtering (SBSIF) method, is proposed that considers these dynamic temporal and spatial properties of traffic. In Section 3.2, the SBSIF method and its components are presented and assessed. In Section 3.3, the proposed methodology is applied to a segment of I-287. This is followed by an estimation of the benefits in terms of the savings in number of secondary incidents that are achieved through a reduction in delay resulting from primary incidents that is due to the FSP program.

3.2 SBSIF Method

The SBSIF method is composed of two main tasks. The first task identifies the incident impact area that results from each primary incident, i.e. the portion of the time-space traffic speed contour map in which traffic speeds are impacted as a consequence of the incident. The second task employs the impact area to identify the secondary incidents from archived data. The identification of an incident as secondary to a primary incident is illustrated in Figure 3.1. Given the incident impact area that is created by an incident “A”, incident “B” is classified as a secondary incident.

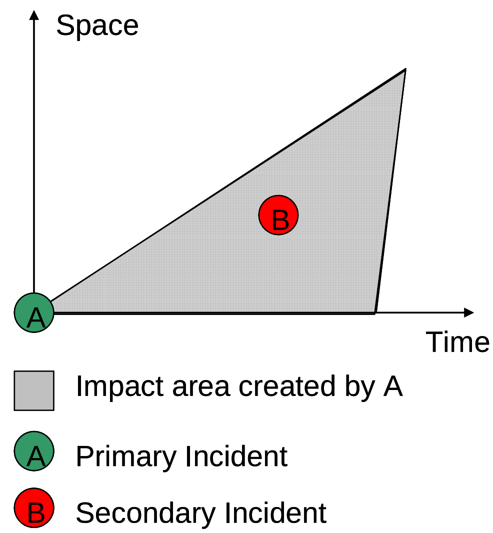

Figure 3.1 Concept for classifying a secondary incident

Direct measurement of the impact area for every incident as is required for the first task is computationally burdensome. Thus, to facilitate this task, an approach that develops regression models from archived incident data for use in estimating the impact area for incidents with given properties under given traffic conditions is proposed. The regression models can be employed in estimating geometrical properties of the impact area associated with a primary incident that are necessary for delineation of the boundaries of this area.

In the proceeding subsection, the specific steps of the SBSIF method and the regression modeling technique are described.

3.2.1 Procedures of the SBSIF Method

The steps of the SBSIF method, assuming that the necessary regression models exist for estimating the corner points for delineation of the impact area boundaries, are given in Figure 3.2. The regression models are described in detail in Subsection 3.2.1.2.

Let P denote the set of incidents archived in an incident database arising along a roadway segment during a given study period, $P = \{p_{it} \mid t \in \Gamma = \{1,2,...T\}, i \in (1,2,....n_t)\}$, where p_{it} represents incident i, $i \in (1,2,....n_t)$, of incident type t, Γ is the set of incident types, n_t is the number of incidents of type t, and $\sum_{t \in \Gamma} n_t = |P|$. The initial step of the SBSIF method defines two subsets of incidents in the archived database P: primary incidents and potential secondary incidents, denoted by $Q_p \subseteq P$ and $Q_s \subseteq P$, respectively. The user can select the types of incidents that belong to Q_p. Let $\Omega \subseteq \Gamma$ be the set of types of incidents that belong to Q_p as determined by the user. Ω represents the set of incident types for which the user would like to determine the set of resulting secondary incidents. $Q_p = \{p_{ik} \mid i = (1,2,....n_k), k \in \Omega\}$ and $\sum_{k \in \Omega} n_k = |Q_p|$. For example, a user might be interested to determine the set of secondary incidents to primary incidents from only the collision accident category, only the disabled vehicle category, both or any other classification of the incidents in an archived database. Moreover, all incidents in the database can be regarded as primary incidents, in which case all types of incidents would be included in Ω, i.e. $\Omega = \Gamma$ and $Q_p = P$. Similarly, Q_s is defined as the collection of incidents of type Λ, $\Lambda \subseteq \Gamma$, where Λ, denotes the chosen classes of incidents to be considered as possible secondary incidents to incidents in Q_p. $Q_s = \{p_{ij} \mid i = (1,2,....n_j), j \in \Lambda\}$ and $\sum_{j \in \Lambda} n_j = |Q_s|$. For example, an incident of the collision accident type may be included in Q_s, whereas, incidents of the disabled vehicle type may not.

Step 0: $S = \phi$
Step 1: Generate a corner point set, $C_{p_{ik}}$, of incident $p_{ik} \in Q_p$ via regression models with traffic conditions and incident properties.
Step 2: Let x-y coordinates of $p_{ik} \in Q_p$ be the point of origin, $(0,0)$. Form the impact area, $IA_{p_{ik}}$, of incident $p_{ik} \in Q_p$ using line functions with the corner point set, $C_{p_{ik}}$.
Step 3: Compute x-y coordinates, $(x,y)_{p_{ij}}$, for a potential secondary incident, $p_{ij} \in Q_s$, with data logs of mile marker and incident start timestamp with respect to $p_{ik} \in Q_p$.
Step 4: If $(x,y)_{p_{ij}} \in IA_{p_{ik}}$ and the traffic flow direction of p_{ij} is the same as p_{ik}, a primary-secondary pair is found, denoted (p_{ik}, p_{ij}).

Step 5: $S = S \cup \{(p_{ik}, p_{ij})\}$. Repeat steps 3 and 4 for all $p_{ij} \subseteq Q_s$ and $p_{ij} \neq p_{ik}$.

Step 6: Repeat step 1 to step 5 for all $p_{ik} \subseteq Q_p$,

where

Q_p	:	Set of primary incidents consisting of Ω incident types, $Q_p = p_{ik} \forall i \in (1,2,....n_k), \quad \Omega \subseteq \Gamma$
p_{ik}	:	An incident, i, of incident type k, $\forall i = (1,2,...n_k), k \in (1,2,...K)$, $p_{ik} \in Q_p$
Q_s	:	Set of potential secondary incidents consisted of Λ incident types, $Q_s = p_{ij} \forall i \in (1,2,....n_j), \quad \Lambda \subseteq \Gamma$
p_{ij}	:	An incident, i, of incident type j, $\forall i = (1,2,...n_j), j \in (1,2,...J)$, $p_{ij} \in Q_s$
S	:	Set of primary-secondary incident pairs, $S = \{(p_{ik}, p_{ij})\} \forall p_{ik} \in Q_p, p_{ij} \in Q_s$
(p_{ik}, p_{ij})	:	A primary-secondary incident pair $\forall p_{ik} \in Q_p, p_{ij} \in Q_s$
$C_{p_{ik}}$	:	Set of corner points of incident $p_{ik}, \forall p_{ik} \in Q_p$
$IA_{p_{ik}}$	:	Impact area of incident $p_{ik}, \forall p_{ik} \in Q_p$
$(x, y)_{p_{ij}}$	:	x-y coordinates of incident $p_{ij}, \forall p_{ij} \in Q_s$

Figure 3.2 The SBSIF method

The SBSIF method classifies an incident in Q_s as a secondary incident by determining whether or not the incident falls within the impact area of any incident in Q_p. In steps 1 and 2 of the SBSIF method, regression models are employed to identify the corner points of an incident's impact area. Alternatively, one could identify such corner points directly through analysis of traffic data. Specifically, one can develop a traffic flow contour map, as in Figure 3.3 of Section 3.2.1.1, from traffic detector data to capture the impact of an incident given the incident's characteristics and prevailing traffic conditions. As it is often the case that such data is unavailable, simulation can be employed to estimate the required traffic data to develop such contour maps. Since the necessary traffic detector data may not be available and replications of the incidents using a simulation package can be quite time-consuming, multiple regression models are developed that can be employed in defining the impact area in this step of the SBSIF method. In Section 3.2.1.1, detailed description of the incident impact area delineation through corner point identification is given. In Section 3.2.1.2, the multiple regression model approach to identifying the corner points of the incident impact area for any incident with given properties under given traffic conditions prior to the onset of the incident is described.

In step 1 of the SBSIF method, multiple regression models are applied to generate a set of corner points, $C_{p_{ik}}$, associated with individual incident properties and prevailing traffic conditions for an incident $p_{ik} \in Q_p$. Equations of the line segments formed through neighboring pairs of corner points are determined in step 2. These equations are used to delineate the boundaries of the impact area, $IA_{p_{ik}}$, of incident $p_{ik} \in Q_p$. The x-y coordinates in time and space of the primary incident, p_{ik}, under consideration is set to origin $(0,0)_{p_{ik}}$.

In step 3, the temporal and spatial x-y coordinates, $(x, y)_{p_{ij}}$, of each incident p_{ij} in Q_s, are computed with respect to the primary incident's start timestamp and location given by the mile-marker data log. If the x-y coordinates of incident p_{ij} fall within the impact area generated by the primary incident p_{ik}, incident p_{ij} is classified as a secondary incident in step 4. A primary-secondary incident pairing is made, denoted (p_{ik}, p_{ij}). This process (steps 3 and 4) is repeated over all incidents in Q_s (via step 5). Steps 1 through 5 of the algorithm are repeated over all incidents Q_p. Note that it is possible that more than one secondary incident will be associated with the same primary incident. Moreover, as Q_p may intersect Q_s, this method can help to identify tertiary (i.e. secondary incidents of secondary incidents) and higher orders of incidents.

3.2.1.1 Impact Area Analysis

An illustrative incident impact area contour map generated from simulation of traffic for a given incident is provided in Figure 3.3. The shape of the contour map is sensitive to the incident properties and prevailing traffic conditions. The impact area can be identified based on user defined performance measures, such as speed, volume or occupancy, and thresholds for level of service. For example, in the figure, existing travel speeds are compared with pre-incident travel speeds in incident impact area identification. One can see the boundary of the discontinuous region of traffic flow in Figure 3.3, which forms a dynamic region within which an incident can be classified as a secondary incident.

Using a threshold value for average speed from pre-incident conditions, one can form a time-space polygon to represent the impact area. Different threshold values will lead to different polygon representations. The incident impact area for the illustrative example is identified as the area for which a decrease in speed to a value less than 50% or 75% of the average pre-incident speed is noted (shown in red or yellow for 50% or 75% thresholds, respectively, in Figure 3.4). For a chosen threshold value, any incident occurring within the identified time-space polygon generated by a primary incident can be classified as a secondary incident.

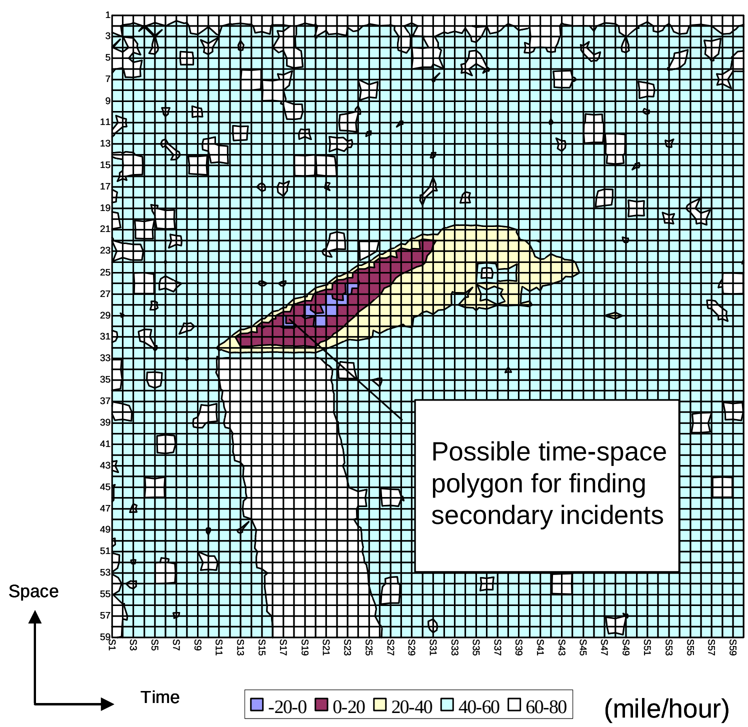

Figure 3.3 Traffic flow characteristic contour map of an incident

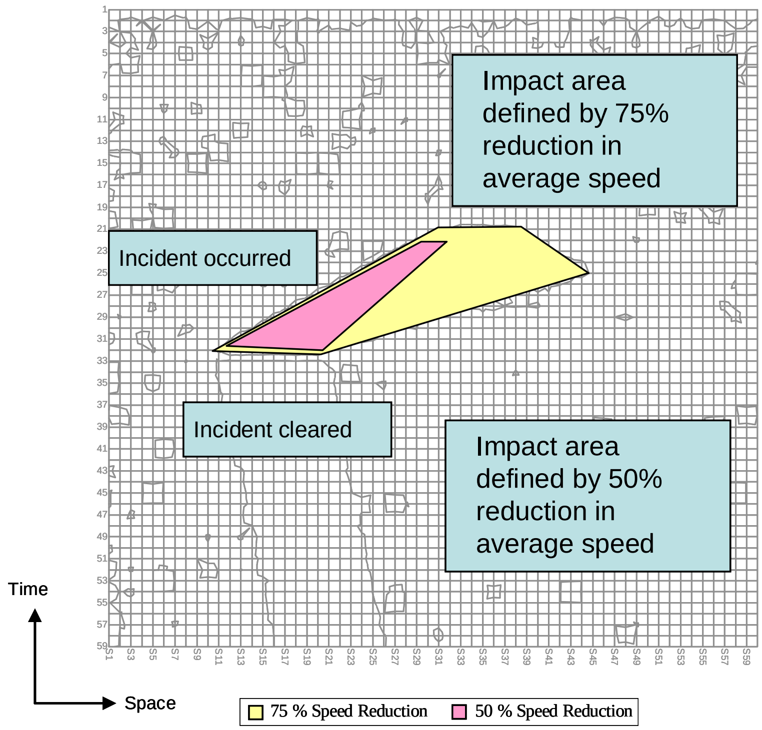

Figure 3.4 Impact area with two threshold definitions

Once the incident impact area contour map is obtained, it can be visually inspected and the (x,y) coordinates of the corner points of the impact area can be identified as shown in Figure 3.5.

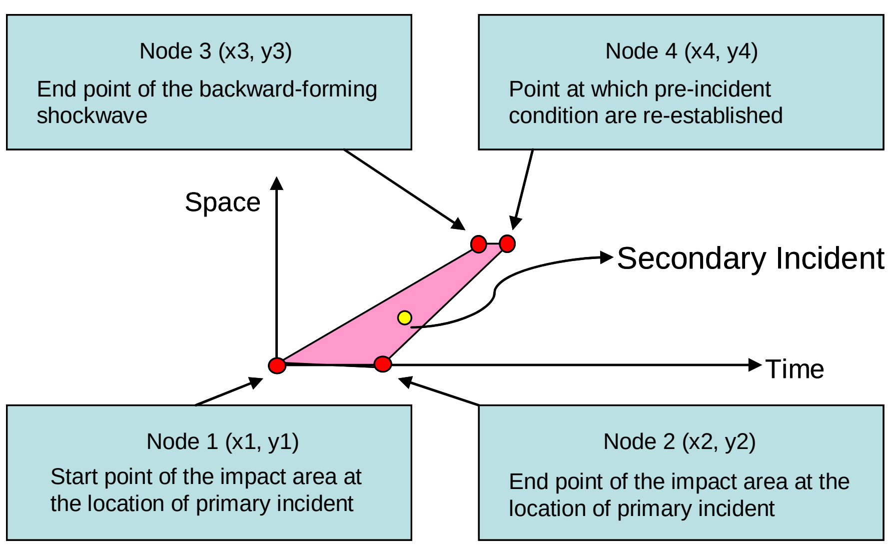

Figure 3.5 Impact area identification through corner point identification

Typically, four corner points are required to specify the polygon used for delineating the incident impact area; although, in some situations, the polygon may consist of only 2 or 3 corner points. One can interpret each corner point as follows.

Node 1: Incident Start Point

The first node represents the incident origin at incident onset.

Node 2: Incident End Point

The second node represents the incident origin at the time of incident clearance (i.e. the time at which traffic conditions return to pre-incident levels). Thus, this node represents the same location as Node 1, but at a later time.

Node 3: Point of Shockwave Transition

The third node represents the location and point in time at which the backward-forming shockwave (identified by temporal and spatial boundary conditions that demark a discontinuity in flow-density conditions (May, 1990)) terminates.

Node 4: End of Incident Impact

The fourth node represents the location and time at which pre-incident traffic conditions are re-established.

The x-value associated with each corner point is a measure of time and the y-value is a measure of space. With the knowledge of the (x,y) coordinates associated with each of the corner points, the polygon can be completely specified. The sides of the polygon are computed from the (x,y) coordinates of their endpoints using the equation of a line. For example, given two corner points (x1,y1) and (x2, y2), the equation of a line is given as:

$$y = y1 + [(y2 - y1)/(x2 - x1)] \times (x - x1) .$$

Any incident arising at a time and location associated with an (x,y) coordinate that falls within the polygon formed by the primary incident is classified as a secondary incident. The yellow dot in Figure 3.5 illustrates such a secondary incident.

3.2.1.2 Regression Models for Identifying Corner Points of Impact Areas

Simulation can be employed to create the traffic flow contour map for any given incident and the incident impact area can be identified visually. Since analysis of a historical archive of incident data would require incident impact area identification of hundreds of incidents, this process would be excessively time-consuming. Thus, the use of multiple regression models that, once calibrated, can be employed to identify the impact area of a primary incident given prevailing traffic conditions and incident properties, is suggested herein to facilitate this task. Each of the regression models identifies a corner point of the impact area for an incident with given properties. This approach to incident impact area identification explicitly considers the variability of traffic flow characteristics in the aftermath of an incident, i.e. it is a dynamic approach.

To calibrate the regression models, traffic conditions were simulated under 360 representative incidents along a 10-mile stretch of I-287 using the CORSIM simulation platform. Incidents with a wide range of characteristics under varying traffic conditions were replicated. Specifically, the criteria considered include:

1. Lane blockage: shoulder, 1 and 2 lanes blocked
2. Incident duration: 10, 20 and 30 minutes
3. Speed: 55 and 65 miles per hour
4. Volume: 400 to 2300 vehicles per lane per hour in 100 vehicle increments

By using simulated incident data instead of historical data, a wider range of incident characteristics could be captured.

Each of the 360 representative incidents was simulated over a two-hour period and traffic data was collected from the simulation results. The average speed at one-minute increments was collected over space with 1,000 feet spacing. The incident time-space impact area is identified by first recognizing the stretch of roadway and time intervals for which an average speed reduction by 50% is noted. For each incident, the (x,y) coordinates of the impact area corner points were identified through visual inspection. By connecting the corner points with straight line segments, the impact area is fully delineated. This process is illustrated in Figure 3.6.

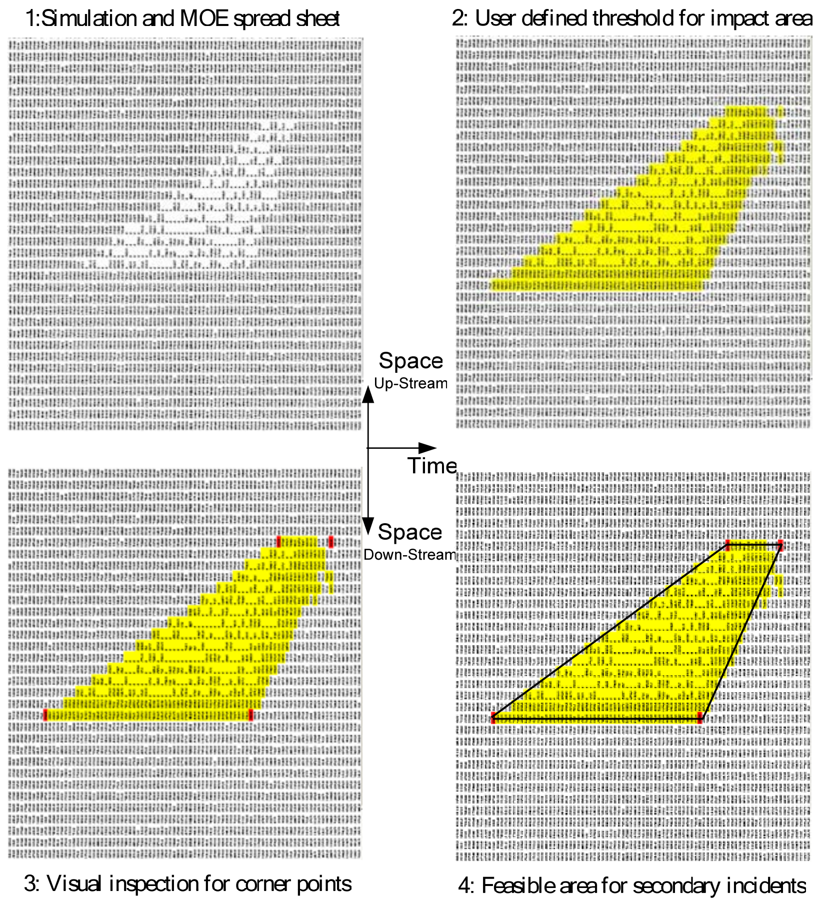

Figure 3.6 Procedures for corner point identification

Data related to 50 of the 360 simulated incidents were discarded, because the resulting impact area expanded beyond the study limits of the 10-mile roadway segment and two hour study period. Thus, it was not possible to obtain the corner points of the impact area associated with these 50 incidents. The final sample size from each scenario classification is provided in Table 3.2.

Table 3.2 Simulation scenario and sample size for regression model calibration

Lane Blockage	Incident Duration (minutes)	Speed (mph)	Volume(vplph)	Qualified sample size
Shoulder	10	55	400-2300	20
		65	400-2300	20
	20	55	400-2200	19
		65	400-2200	19
	30	55	400-2000	17
		65	400-2000	17
1 lane blocked	10	55	400-2200	19
		65	400-2200	19
	20	55	400-2000	17
		65	400-2000	17
	30	55	400-1900	16
		65	400-1900	16
2 lane blocked	10	55	400-2100	18
		65	400-2100	18
	20	55	400-1800	15
		65	400-1900	16
	30	55	400-1600	13
		65	400-1700	14

Table 3.3 gives the independent variables employed within the regression models and provides the correlation matrix of incident duration, volume, and average speed from the 310 samples. As the absolute correlation values between the independent variables are low, it is assumed for simplicity that these variables are uncorrelated. Thus, ordinary least squares regression modeling can be applied. Note that the lane blockage status variables are treated as binary variables.

Table 3.3 Correlation matrix for the independent and dependent variables

		Incident duration	Volume	Average speed	Shoulder blocked	1 lane blocked	2 lanes blocked
Independent variables	Incident duration	1					
	Volume	-0.134	1				
	Average speed	0.045	-0.307	1			
	Shoulder blocked	0.013	0.096	-0.033	1		
	1 lane blocked	-0.068	-0.049	-0.054	-0.574	1	
	2 lanes blocked	0.060	-0.050	0.095	-0.459	-0.465	1
Dependent variables	x2	0.999	-0.126	0.047	0.009	-0.063	0.058
	x3	0.760	0.296	-0.106	-0.109	-0.070	0.194
	y3	0.110	0.675	-0.219	-0.282	-0.026	0.333
	x4	0.666	0.429	-0.095	-0.202	-0.056	0.279
	y4	0.080	0.688	-0.228	-0.272	-0.022	0.318

Two ordinary least squares regression models were calibrated for each corner point, one associated with the x-coordinate and the other with the y-coordinate. Node 1 of each incident impact area is shifted to (x,y)=(0, 0). The y-coordinate for Node 2 is zero and, thus, only the x-coordinate of the second node must be estimated. The estimation of the impact area corner points by this method is illustrated in Figure 3.7.

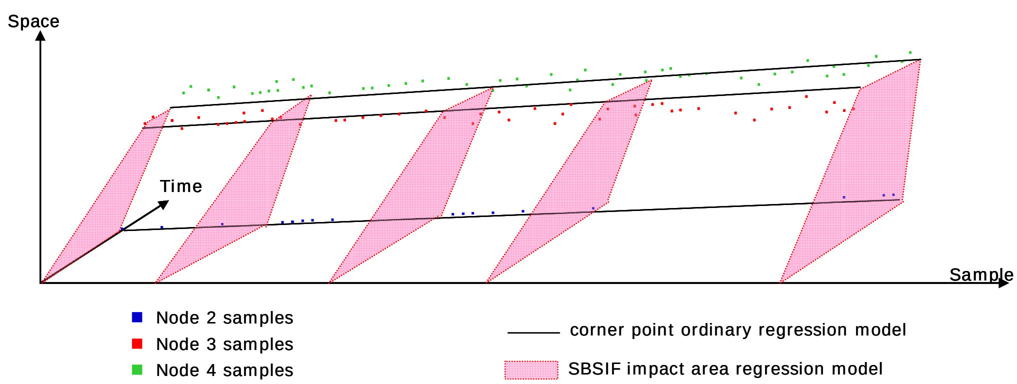

Figure 3.7 Impact area regression models of the SBSIF method

Parameters associated with statistically significant independent variables of the regression models are summarized in Table 3.4. Only the x-coordinates for Nodes 2, 3 and 4 and the y-coordinates for Nodes 3 and 4 require estimation, because x1, y1 and y2 are set to zero. The goodness of fit indicators, R^2 and adjusted R^2, and P-values, are also provided for each regression model. The smaller the p-value, the greater one's confidence is in its significance. The sign of all significant parameters, with the exception of the constant terms, is positive, which is consistent with expectations for the given independent variables. Note that average speed was not significant for Nodes 3 (x3 and y3) and 4 (x4 and y4) and number of lanes blocked was not significant for x2 of Node 2. Thus, these factors were excluded from the final model.

Table 3.4 Multi regression models of the SBSIF method

	x2	x3	y3	x4	y4
Variable	Coefficient [P-value]	Coefficient [P-value]	Coefficient [P-value]	Coefficient [P-value]	Coefficient [P-value]
Constant (C)	-0.53401 [.010]	-11.4352 [.000]	-13.8086 [.000]	-18.9505 [.000]	-14.0318 [.000]
Incident duration	0.997692 [.000]	1.08343 [.000]	0.170031 [.000]	1.19827 [.000]	0.152125 [.000]
Volume	1.59E-04 [.000]	8.90E-03 [.000]	0.010055 [.000]	0.01435 [.000]	0.01061 [.000]
Average speed	8.42E-03 [.011]	-	-	-	-
1 lane blocked	-	2.39768 [.001]	3.53768 [.000]	5.06702 [.000]	3.61839 [.000]
2 lanes blocked	-	5.28852 [.000]	7.43028 [.000]	10.4489 [.000]	7.50181 [.000]
R^2	0.998822	0.775601	0.669801	0.811807	0.666523
Adjusted R^2	0.99881	0.772658	0.665471	0.809339	0.66215

The regression model parameters provided in Table 3.3 were estimated with representative incidents (i.e. the 310 simulated incidents). To further evaluate these models, estimated corner points are compared with corner points for the archived incident study data associated with the same roadway segment from the first half of 2006. The necessary traffic data (i.e. traffic volume and speed) only became available in 2007. Thus, as in Chapter 2, in the absence of 2006 traffic data, average monthly traffic data for a similar time period in 2007 was employed. Simulation is used to replicate post-incident traffic conditions for the incidents in the archived data set.

The archived incident data for the study segment of I-287 and study period consists of 1,303 incidents. These incidents can be classified into three groups: “with H.E.L.P.,” “without H.E.L.P.,” and “both H.E.L.P. and trooper.” The chosen classification is a function of the type of response given to the incident. A portion of this archived incident data was considered in assessing the calibrated regression models. Specifically, 693 incidents with response from the H.E.L.P. program, i.e. “with H.E.L.P.,” from the database were employed in the assessment. These incidents were replicated in the CORSIM simulation platform with their incident properties and prevailing traffic conditions as estimated from the 2007 traffic data. Results of the simulation were employed to create contour maps of the incident impact areas and the corner points of the impact area associated with each incident were visually identified. Visually identified corner points were compared with comparable corner points estimated by the proposed regression models.

Plots of predicted vs. visually estimated corner point (x,y) coordinates for Nodes 3 and 4 are provided in Figure 3.8. The closer to the diagonal, the closer the predicted value is to the visually estimated value. Resulting corner point coordinates from both visual identification and regression modeling estimation approaches are given in Table 3.5 for an arbitrary sample of incidents. Note that no samples with y-value of zero are included in the sample.

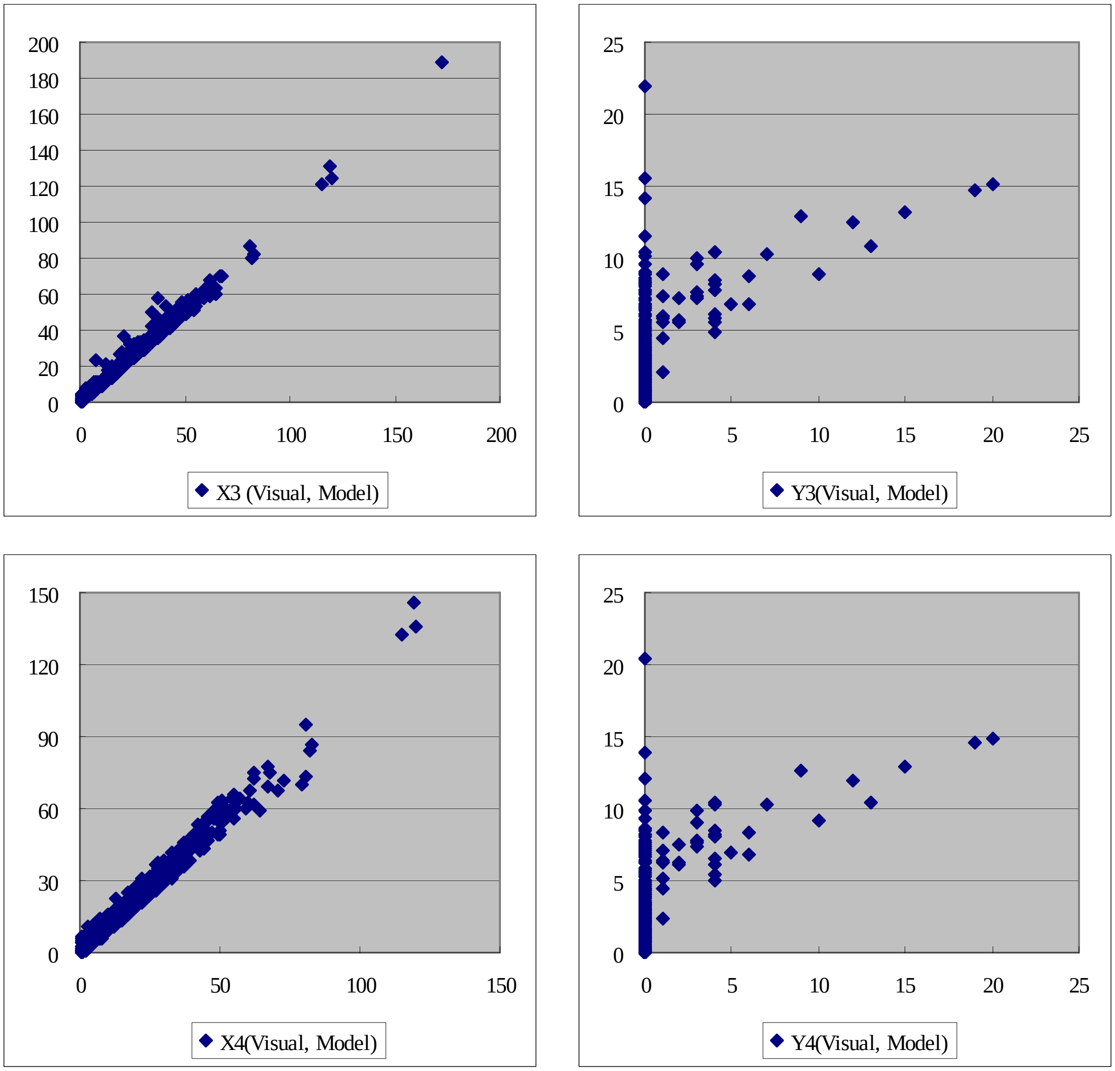

Figure 3.8 Corner point prediction trend via regression models

Table 3.5 Comparison of corner point coordinate estimates

	Visually Identified Corner Point Coordinates								Regression Model Predictions of Corner Point Coordinates							
Corner point / Incident Case	x1	y1	x2	y2	x3	y3	x4	y4	x1	y1	x2	y2	x3	y3	x4	y4
173	**0**	**0**	**17**	**0**	**19**	**4**	**23**	**4**	**0**	**0**	**16**	**0**	**21**	**6**	**26**	**6**
175	**0**	**0**	**27**	**0**	**26**	**3**	**32**	**3**	**0**	**0**	**26**	**0**	**32**	**8**	**37**	**8**
187	**0**	**0**	**10**	**0**	**8**	**1**	**11**	**1**	**0**	**0**	**9**	**0**	**11**	**2**	**13**	**2**
212	**0**	**0**	**14**	**0**	**15**	**4**	**20**	**4**	**0**	**0**	**13**	**0**	**19**	**8**	**25**	**8**
215	**0**	**0**	**35**	**0**	**21**	**1**	**36**	**1**	**0**	**0**	**34**	**0**	**37**	**6**	**42**	**5**
248	**0**	**0**	**51**	**0**	**58**	**15**	**71**	**15**	**0**	**0**	**50**	**0**	**59**	**13**	**68**	**13**
249	**0**	**0**	**7**	**0**	**8**	**2**	**10**	**2**	**0**	**0**	**6**	**0**	**11**	**6**	**15**	**6**

To test the effectiveness of the proposed regression modeling approach in estimating the coordinates of the corner points used in impact area delineation and ultimate identification of secondary incidents, the SBSIF method described in Section 3.2.1 was employed twice. In one run of the method, the corner points from visual inspection were used and step 1 was omitted. In the other run, the corner points were estimated by regression as indicated in the SBSIF method description. The 693 “with H.E.L.P.” incidents of the 1,303 archived incidents were considered as potential primary incidents to secondary incidents and all collision incidents under all response categories (i.e. “with H.E.L.P.,” “without H.E.L.P.,” and “both H.E.L.P. and trooper”) were considered as potential secondary incidents, resulting in 630 such incidents of the 1,303 archived incidents.

The SBSIF method identified 24 and 27 incidents as secondary incidents employing the visual and regression methods for corner point identification, respectively. In fact, with the exception of the three additional incidents identified with the use of the regression models, these approaches identified the same set of 24 incidents as secondary incidents. The additional three incidents were found within the boundary of the impact area as delineated through the SBSIF method (steps 1 and 2) with the use of the regression models.

3.2.2 Assessment of the SBSIF method

By considering traffic dynamics, the proposed SBSIF method overcomes the drawbacks of the static threshold filtering methods that have been proposed in the literature. These static methods would identify an erroneous impact area and, therefore, would identify erroneous secondary incidents (positive error) or would fail to identify incidents as secondary (negative error). An example from the archived data to illustrate a positive-type error is provided in Figure 3.9, where the static method identifies an incident as secondary that would not be considered secondary if one considers the impact area correctly.

The impact area, as determined by both visual inspection and the SBSIF method, is delineated in the figure. Incident cases 1204 and 1205 would be classified as secondary incidents by the static threshold method using 15-minute and 2-mile thresholds as proposed by Zhan et al. (2007). Similarly, using the more conservative threshold of 1-mile in conjunction with the 15-minute threshold as proposed by Raub (1997), only incident number 1204 would be classified as a secondary incident. Neither incident, however, appears to be a secondary incident when the impact area of primary incident number 494 is correctly considered.

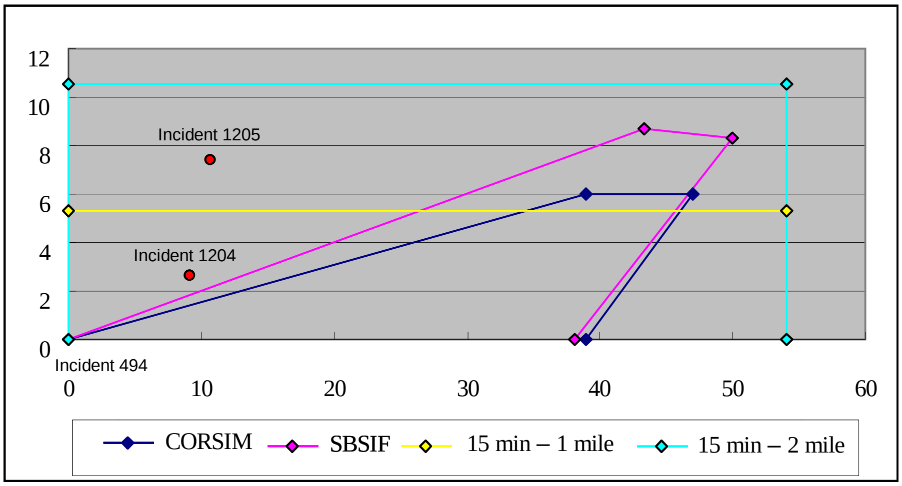

Figure 3.9 Secondary incident classification by static and dynamic methods

To assess the accuracy of the proposed regression models for identifying the impact area corner points, results of the SBSIF method employing the regression models in step 1 are compared to the method when visual inspection is employed in delineating the impact area in place of steps 1 and 2. Results of this comparison, as well as a comparison with the static threshold methods, are provided in Table 3.6. The table includes the number of both positive and negative errors as compared with the SBSIF approach employing the impact area as determined visually.

Table 3.6 Error comparison between SBSIF and other methods

	Filtering method			
	CORSIM (Visual)	SBSIF (Regression)	15 minutes and 1 mile	15 minutes and 2mile
Positive error	-	3	17	23
Negative error	-	0	0	0
Number of secondary incidents identified	24	27	41	47

Results given in Table 3.5 indicate that the SBSIF method with regression modeling significantly outperforms the static methods. The static methods identify as many as twice the incidents as secondary as compared with those identified through visual inspection. By contrast, the error of the SBSIF method with regression was only 12% (as compared with 70 or 100%).

Similar results from the Iliescu and Haghani (2006) technique as compared to the proposed SBSIF method are expected if small increments of time are employed in searching for secondary incidents that fall within the impact area. However, such a technique will require excessive computational effort as compared with the proposed SBSIF method. If larger time increments are employed, significant errors may occur. Whether or not the errors are of a negative or positive variety depends on the specific details of its implementation.

To employ the progression curve method proposed by Chilukuri and Sun (2006), estimates of maximum queue lengths are required. Since no such data is available, this method could not be tested. It is worth noting, too, that in addition to the difficulties associated with implementing their approach due to such data requirements, this method employs a single curve for all incidents, regardless of the number of lanes that are blocked by the incident and prevailing traffic conditions. Thus, it is likely that such a method will result in both positive and negative errors in secondary incident identification.

3.3 Secondary Incidents along I-287

During the study period along the 10-mile study segment of I-287, 1,303 incidents arose along I-287, 693 of which received assistance from the H.E.L.P. program. Through H.E.L.P. assistance, the incident duration is shortened, thereby reducing the traffic impact area of the initial incident. To evaluate the benefits in terms of secondary incident savings due to this reduction in impact, the number of secondary incidents caused by the 693 H.E.L.P. assisted incidents must be identified. Only 630 of the 1,303 incidents were considered to be potential secondary incidents. The remaining 673 incidents belonged to the disabled vehicle category. Note that the set of 630 incidents intersect with the set of 693 incidents.

The SBSIF method using regression modeling to identify corner points was applied and 27 incidents were classified as secondary incidents to these 693 H.E.L.P. assisted incidents (nearly 4% secondary incident rate). These computations were repeated considering both H.E.L.P. and trooper assisted incidents (i.e. the entire dataset); however, information pertaining to lane blockage was not recorded for many of the trooper-handled calls. Thus, only 992 of the 1,303 incidents were considered in this wider analysis. The results and the corresponding secondary incident rates, including results from the static threshold methods, are provided in Table 3.7.

Table 3.7 Comparison of secondary incident rate estimates along the I-287 segment

	Secondary incident rate with H.E.L.P. (693 potential primary incidents)		Overall secondary incident rate with and without H.E.L.P. (992 potential primary incidents.)	
	No. of secondary incidents	No. of secondary incidents/number of primary incidents	No. of secondary incidents	No. of secondary incidents/number of primary incidents
SBSIF model (dynamic)	27	3.9 %	48	4.8 %
1-mile, 15-minute static thresholds	41	5.9 %	73	7.4 %
2-mile, 15-minute static thresholds	47	6.8 %	82	8.3 %

As one might expect, the number of secondary incidents as a percentage increased by approximately one percent when the larger dataset was considered. This is consistent with the fact that the H.E.L.P. program assists more disabled vehicles than do troopers. Such incidents require significantly less time than incidents involving a collision, which make up a large portion of the incidents addressed by troopers. Moreover, a collision is more likely to result in a larger impact area as compared with an incident involving a disabled vehicle.

Note that the 693 incidents assisted by the H.E.L.P. program incurred less incident duration than they would have had they not received such assistance. Thus, one can presume that additional incidents (i.e. secondary to these 693 incidents) would have resulted had the H.E.L.P. program not been in place.

3.4 Benefits in Savings in Secondary Incidents

In Section 3.3, secondary incidents were identified. It is difficult to estimate savings in secondary incidents, because such savings can only be concluded from incidents that did not occur, which cannot be documented. Thus, to estimate such savings in secondary incidents that would result from the H.E.L.P. program, a formula is proposed.

The proposed secondary incident estimation formula assumes that the number of secondary incidents is linearly correlated with total delay. It is reasonable to assume that the larger the impact area, the more likely a secondary incident is to occur. A related assumption is employed by CHART in evaluating secondary incidents for Maryland (Chang and Rochon, 2006). They assumed that the savings in secondary incidents are linearly correlated with incident duration. However, total delay may be more pertinent than incident duration, because it reflects not only the temporal properties of the impact area, but also the spatial properties. Such properties are recognized even in the static threshold methods. Moreover, total delay is a reasonable surrogate for impact area size.

Equation (3.1) is proposed for estimating the number of secondary incidents as a function of incident duration extended cases (5 minutes to 25 minutes):

$$N^{e,k} = \frac{N^b * TD^{e,k}}{TD^b} \qquad (3.1),$$

where

N^b	:	Number of secondary incidents found in the database,
$N^{e,k}$	:	Number of secondary incidents for k-minute incident duration extension case, $k = (5, 10, 15, 20, 25)$,
TD^b	:	Total delay for the base case (no extension for incident duration), and
$TD^{e,k}$	:	Total delay for k-minute incident duration extension cases, $k = (5, 10, 15, 20, 25)$.

Total delay based on the base case and extension cases, TD^b and $TD^{e,k}$, respectively, were estimated from replicating the incidents via simulation as discussed in Chapter 2 and shown in Table 3.8.

During the study period, there were 693 incidents with response from the H.E.L.P. program that induced a total travel delay of 36,374 vehicle-hours. If the incident duration of these 693 incidents were extended to reflect the actual time that would have occurred had the H.E.L.P. program not existed, one could compute the savings in total delay through simulation. That is, it was assumed that the incident duration of a given incident that received assistance from the H.E.L.P. program was 20 minutes and that the H.E.L.P. program reduced the incident duration by 10 minutes (i.e. the incident would have required 30 minutes for resolution). Two simulation runs could be conducted, one assuming an incident duration of 20 minutes and a second of 30 minutes. The savings in total delay could be estimated from the difference in total delay between the two runs. This approach was employed on the 693 H.E.L.P. assisted incidents assuming between 5 and 25 minutes in incident duration savings in 5-minute increments. The total delay for each increment was computed and equation 3.1 was employed in the process of estimating the number of secondary incidents that were avoided as a consequence of the H.E.L.P. program. The resulting estimates are provided in Table 3.8.

Table 3.8 Number of secondary incidents along the I-287 segment under varying incident duration extension cases

Incident duration extension case	Base case	5 minutes	10 minutes	15 minutes	20 minutes	25 minutes
Total delay (vehicle-hours)	36,374	38,932	41,803	45,007	48,557	53,178
Number of secondary incidents	27	29	31	33	36	39

Table 3.8 indicates a savings in secondary incidents of between 2 (29 as compared with 27) and 12 (39 as compared with 27) incidents as a result of the H.E.L.P. program assuming between 5- and 25-minute reductions in incident duration, respectively. Note that these estimates are likely to be conservative, because the actual duration of these 693 incidents would have been greater had the H.E.L.P. program not been in place and a greater number of secondary incidents would be expected than were actualized.

3.5 Conclusions

To evaluate the benefits of the H.E.L.P. program in terms of savings in secondary incidents, a filtering methodology, the SBSIF method, was developed to identify secondary incidents from an incident data archive. This methodology overcomes the shortcomings of many of the approaches for secondary incident classification that have been proposed in the literature. The method was applied on the study data for a 10-mile segment of I-287 and 27 incidents of 1,303 archived incidents were identified as secondary.

Results from this technique were compared with those from standard static methods and visual inspection. These results indicate that the rate of misclassification for the static method far exceeds that of the proposed SBSIF method. In fact, while the SBSIF method erroneously identified three incidents as secondary, the more common static methods erroneously identified as many as 23 incidents as secondary incidents. In addition, the proposed methodology outperforms other dynamic methods in terms of either computational efficiency or classification error likelihood.

The SBSIF method can be most effectively implemented with the use of the proposed regression modeling technique for impact area corner point identification. The regression models developed herein were calibrated on data for a 10-mile segment of I-287. While these models may have direct applicability to other roadways with similar geometry and incident characteristics, additional regression models would need to be calibrated for use in impact area identification for roadways with different geometric design or significantly different incident properties. To further refine the regression models, additional factors, such as weather, might be considered. The greater the explanatory power of the set of chosen independent variables, the more accurate the models. However, the fewer the independent variables required to obtain reasonable estimates of the impact area corners points, the less data that will be required and the more practical the models will be.

To estimate the savings of the H.E.L.P. program, the number of secondary incidents that might be expected is assumed to be linearly correlated with total delay incurred as a consequence of a primary incident. Assuming savings in incident duration due to the H.E.L.P. program of between 5 and 25 minutes, between 2 and 12 secondary incidents are estimated to have been avoided as a consequence of the program. While reasonable, this assumption of linearity requires validation. Additional study would be required to assess the mathematical relationship between secondary incident savings and travel delay reduction or improvements in other traffic measures.

CHAPTER 4

Benefit/Cost Analysis

A widely employed method for assessing the benefits of FSP programs around the country involves the estimation of equivalent monetary savings from savings in travel delay, emission pollution, fuel consumption and secondary incidents. In this chapter, such a methodology is used in conjunction with operating cost estimates in assessing the B/C ratio of the H.E.L.P. program. In Section 4.1, conversion rates for estimating the monetary equivalents of delay, emissions, fuel consumption and secondary incidents employed within the literature are reviewed. In Section 4.2, the B/C ratio for the H.E.L.P. program is estimated and general conclusions are provided in Section 4.3.

4.1 Monetary Equivalents and FSP benefits

Conversion rates employed within the literature in assessing the monetary equivalent of travel delay, emissions, fuel consumption and secondary incidents as it relates to FSP programs within the United States are provided in this section. The monetary conversion rates associated with travel delay, emissions and fuel consumption as used in assessments of FSP programs in Massachusetts, Minnesota, Georgia, Maryland, Virginia, and New York are summarized in Table 4.1. Latoski (1999) estimated the monetary equivalent of a single incident at $1,353, assuming the collision involves only property damage, and Haghani and Iliescu (2006) adjusted this rate (to $1,706 per incident with only property damage) based on the 2006 Hudson Valley consumer price indices (CPI).

Table 4.1 Monetary value in dollars of travel delay and emissions

State (evaluation year)	Fuel	Carbon Monoxide (CO)	Hydrocarbons (HC)	Nitrogen Oxide (NO)	Travel Delay
MA (1997)	1.5/gallon	.02/kg	.23/kg	.76/kg	10
MN (2004)	1.56/gallon	3,371/ton	1,774/ton	3,625/ton	10.04 (per person) 18.61 (commercial vehicle)
NY (2006)	2/gallon	6360/ton	6700/ton	12,875/ton	15 (PC*)
GA (2007)	1.52/gallon	6360/ton	6700/ton	12,875/ton	17.23 (PC) 32.15 (Truck)
MD (2007)	1/gallon	6360/ton	6700/ton	12,875/ton	19.58 (Truck) 14.34 (PC)
VA (2008)	2.25/gallon	-	-	-	13.45 (PC) 71.05 (Truck)

* PC (personal car): rate does not consider vehicle occupancy.

4.2 Estimating the B/C Ratio for the H.E.L.P. Program

4.2.1 Estimated Benefits

In Chapter 2, for the study segment of I-287 during the six-month study period, savings in travel delay, fuel consumption and pollutant causing emissions as a consequence of the H.E.L.P. program were estimated. Likewise, for the same study roadway segment and study period, savings in the number of secondary incidents as a result of this program were estimated in Chapter 3.

Let B_{pm}^{k} denote the total benefit in terms of a given performance measure, pm, for $pm \in$ {travel delay; fuel consumption; HC, CO, and NO emissions; secondary incidents}, assuming a k-minute incident duration reduction for $pm \in$ {travel delay; fuel consumption; HC, CO, and NO emissions}, or a k-minute incident duration extension for $pm \in$ {secondary incidents} as described in Chapters 2 and 3, respectively. Extending equation (2.1) provided in Chapter 2 for estimating the savings in performance measure $pm \in$ {travel delay; fuel consumption; HC, CO and NO emissions} for each of 12 categories ($j \in$ {1,2,…,12}) of traffic level and lane blockage scenarios, B_{pm}^{k} can be computed as given in equation (4.1) given notation defined in Section 2.2 of

Chapter 2.

$$B_{pm}^{k} = \sum_{\forall j}\sum_{i\in j}(pm_i^{e,k} - pm_i^{b})_j \quad (4.1).$$

Savings in the number of secondary incidents were estimated in Chapter 3 (provided in Table 3.7) by taking the difference in the number of secondary incidents identified in the data archives (i.e. the base case), denoted N^b, and the number estimated given the additional travel delay that would be incurred in the k-minute incident duration extension cases, $N^{e,k}$. B_{pm}^{k} for $pm \in${secondary incidents} can be expressed as in equation 4.2.

$$B_{pm}^{k} = N^{e,k} - N^{b} \quad (4.2).$$

Let P_{pm} be the monetary equivalent for each unit of savings in performance measure $pm \in${travel delay; fuel consumption; HC, CO and NO emissions; secondary incidents}. The total savings, TB^k, in all performance measure categories (travel delay, fuel consumption, emissions and secondary incidents) from the program given k-minute incident reductions or extensions as appropriate can be estimated by equation 4.3.

$$TB^{k} = \sum_{\forall pm}(P_{pm} \times B_{pm}^{k}) \quad (4.3).$$

Results in terms of total benefits, TB^k, for the I-287 study segment and given study period are provided in Table 4.1. The monetary equivalent rates (i.e. P_{pm}) assumed in this study are given in the table. Note that these rates are based on 2006 values and are quite conservative. For example, it is assumed that the cost of one hour of delay is only $15/vehicle-hour of delay regardless of vehicle classification or vehicle occupancy. These results indicate that, assuming an average reduction in incident duration of 20 minutes (i.e. k = 20), the H.E.L.P. program led to an equivalent savings of $215,000, or an annual savings of $430,000, for the 10-mile study segment and six-month study period.

4.2.2 Estimated Costs

The total cost, TC, is a function of the number of roving FSP trucks along the study segment, hourly operating cost per truck, number of working hours, and number of workdays in the study period, as expressed by equation (4.4).

$$TC = c \times n \times hr \times day \qquad (4.4),$$

where

TC	:	Total cost for operating the FSP program in dollars,
c	:	Cost per truck-hour,
n	:	Number of roving trucks,
hr	:	Number of working hours in each day, and
day	:	Number of workdays in the study period.

Cost estimates of $40 and $50/truck-hour were provided by the H.E.L.P. program personnel. Two roving trucks operated within the study roadway segment with an eight-hour workday. These trucks operated during 126 workdays within the study period. Thus, by equation (4.4), the operational costs along the study roadway segment during the study period were estimated at $80,640 and $100,800 for $40 and $50/truck-hour, respectively.

4.2.3 The B/C Ratio

Results from Sections 4.2.1 and 4.2.2 can be combined to assess the B/C ratio for the H.E.L.P. program for the study area and study period for each k-minute incident reduction or extension case. These results indicate that the program operates with a B/C ratio of 2.68 assuming a cost of $40/truck-hour for operating the H.E.L.P. program or a 2.14 benefit-to-cost ratio assuming a cost of $50/truck-hour for a k-value equal to 20 minutes. These results are provided in Table 4.2.

To determine the point at which the program breaks even, where the cost of operations is equivalent to the savings achieved by the program, the B/C ratios for each k-minute incident reduction or extension case are plotted against the average estimated incident duration savings. This plot shows that breakeven points were reached at eight and 11 minutes for $40 and $50/truck-hour operating cost rates, respectively. That is, if the cost of operating a H.E.L.P. vehicle is assumed to be $40/truck-hour, the program must save, on average, more than eight minutes in incident duration for the benefits to outweigh the costs. Note that the average savings in incident duration estimated for the H.E.L.P. program (20 minutes) far exceeds this breakeven point even for the assumed higher operational rate of $50/truck-hour.

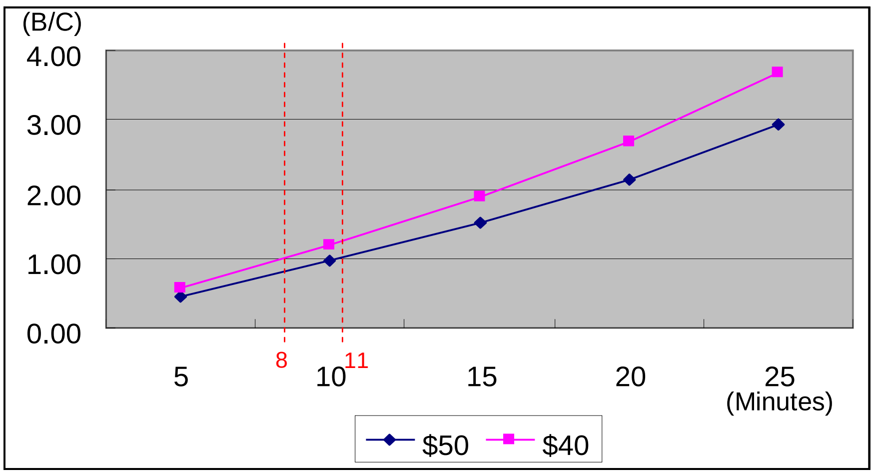

Figure 4.1 B/C versus incident duration reduction by cost

4.3 Conclusions

To evaluate the B/C ratio for the study roadway segment and study period along which the H.E.L.P. program operates, the monetary equivalents of travel delay, fuel consumption, emission pollution and secondary incidents estimated in Chapter 2 and 3 were computed. The equivalents were estimated assuming that the H.E.L.P. program or an equivalent program operating along a similar roadway segment led to a reduction in incident duration of between 5 and 25 minutes (in 5-minute increments) on average.

Findings from this analysis show that the H.E.L.P. program as operated on the study roadway segment is cost effective. Assuming an average reduction in incident duration of approximately 20 minutes (as determined in Miller-Hooks and Chou, 2008), the equivalent of $430,000 in annual savings on the 10-mile segment of I-287 was achieved. These savings were driven by estimated annual savings of:

(a) 24,000 vehicle-hours in travel delay;

(b) 2,900 gallons of fuel consumed;

(c) 0.32 ton of hydrocarbon (HC);

(d) 3.6 tons of carbon monoxide (CO);

(e) 0.2 ton of nitrogen oxide (NO); and

(f) 18 secondary accidents.

Results of the study indicate that the program operates with a B/C ratio of 2.68 assuming a cost of $40/truck-hour for operating the H.E.L.P. program or a 2.14 benefit-to-cost ratio assuming a cost of $50/truck-hour. At an operating cost of $40/truck-hour, to break even, a comparable FSP program would require a minimum of eight minutes reduction in average incident duration (H.E.L.P. reduction is estimated to be 20 minutes) or 11 minutes at an operating cost of $50/truck-hour.

It is the opinion of the authors that these savings are conservative and might even represent a lower bound. That is, the rates employed in estimating the monetary equivalent of savings in the various performance measures are low, particularly for the location in which the H.E.L.P. program operates. No details of traffic composition or passenger occupancy were provided. Thus, traffic was assumed to be made up entirely of personal cars with only one passenger per vehicle. The rate of $15 per vehicle-hour delay is quite low for the region and a much higher rate would be required for truck and commercial vehicle traffic. The rate of $1,706 estimated per secondary incident is also seemingly very low. If only one secondary incident involving a commercial vehicle were to be avoided, much greater savings would be incurred. Additional savings incurred by drivers, including costs of towing, changing of tires or minor repairs, as well as savings to the local community in terms of reduced fatality rates, and thus, reduced lawsuits, roadway closures and the use of forensic teams, for example, might also be included in the B/C ratio estimates.

Table 4.2 Benefit and cost estimation of the H.E.L.P. program for six-month operation along I-287

BENEFIT											
Duration reduction		5 minutes		10 minutes		15 minutes		20 minutes		25 minutes	
Saving	P_{pm} ($/unit)	B_{pm}^{5} (Savings in original units)	TB^{5} (Total savings in dollars)	B_{pm}^{10} (Savings in original units)	TB^{10} (Total savings in dollars)	B_{pm}^{15} (Savings in original units)	TB^{15} (Total savings in dollars)	B_{pm}^{20} (Savings in original units)	TB^{20} (Total savings in dollars)	B_{pm}^{25} (Savings in original units)	TB^{25} (Total savings in dollars)
Delay (vehicle-hours)	15	2,558	38,369	5,429	81,432	8,633	129,488	12,182	182,737	16,804	252,064
Fuel consumption (gallons)	3	399	1,197	733	2,198	1,090	3,271	1,451	4,353	1,761	5,282
HC (tons)	6,700	0.03	224	0.07	476	0.11	756	0.16	1,067	0.22	1,472
CO (tons)	6,300	0.38	2,389	0.80	5,070	1.27	8,061	1.79	11,377	2.47	15,693
NO (tons)	12,875	0.02	206	0.03	438	0.05	696	0.08	982	0.11	1,355
Secondary incidents	1,706	2	3,412	4	6,824	6	10,236	9	15,354	12	20,472
Total saving			45,796		96,436		152,509		215,870		296,337

COST					
	Total Cost $TC = c \times n \times hr \times day$	n Number of roving trucks	hr work hours a day	day work days	c cost per truck hour
COST(1)	100,800	2	8	126	50
COST(2)	80,640	2	8	126	40

B/C RATIOS					
Incident reduction case	5 minutes	10 minutes	15 minutes	20 minutes	25 minutes
B/C ratio (with COST(1))	0.45	0.96	1.51	2.14	2.94
B/C ratio (with COST(2))	0.57	1.20	1.89	2.68	3.67

CHAPTER 5

Findings and Next Steps

In this chapter, key findings from this second study phase are synopsized and suggestions for next steps that might be considered are provided.

5.1 Findings

In Phase I of this study, the reduction in response times and resulting incident durations due to the execution of the H.E.L.P. program were estimated. It was found that an average savings of approximately 20 minutes in incident duration for incidents involving a collision and 19 minutes for incidents involving a disabled vehicle were achieved for the study area as a result of the presence of the H.E.L.P. program (Miller-Hooks and Chou, 2008). The benefits of such reduction in incident duration as it relates to travel delay, fuel consumption, emissions and secondary incidents were estimated in this second study phase. Through detailed study of a 10-mile segment of I-287 over a six month study period in 2006, estimated annual savings of over 24,000 vehicle-hours of delay, 2,900 gallons of fuel consumed, 0.32 ton of hydrocarbons, 3.6 tons of carbon monoxide, 0.2 tons of nitrogen oxide, and 18 secondary incidents were computed, assuming an average incident duration savings of 20 minutes as a consequence of the H.E.L.P. program.

A monetary equivalent of the benefits in travel delay, fuel consumption, emissions and secondary incident reduction was developed and the B/C ratio was estimated under varying average incident reduction scenarios ranging from 5 to 25 minutes. Results of this effort indicate that the program operates with a B/C ratio of 2.68 assuming a cost of $40/truck-hour for operating the H.E.L.P. program or a 2.14 benefit-to-cost ratio assuming a cost of $50/truck-hour. At an operating cost of $40/truck-hour, to break even, a comparable FSP program would require a minimum of eight minutes reduction in average incident duration (H.E.L.P.

reduction is estimated to be 20 minutes) or 11 minutes at an operating cost of $50/truck-hour.

In conclusion, the H.E.L.P. program operates with better than two-to-one benefit-to-cost ratio under very conservative assumptions. It is entirely conceivable that its true benefit-to-cost ratio is significantly greater than two-to-one. Consequently, one can confidently assert that the H.E.L.P. program is justified and provides a sizable return on the public's investment.

5.2 Next Steps

This study has sought to quantify the benefits of the H.E.L.P. program. The savings in terms of travel delay, fuel consumption, emissions and secondary incidents were estimated based on only a three-lane, 10-mile stretch of I-287 and, thus, may not represent the savings for all roadways operated by the H.E.L.P. program. Additionally, the monetary equivalents employed in the B/C ratio estimation were very conservative. Moreover, a linear correlation between travel delay savings and savings in secondary incidents was assumed. This assumption requires validation. In this section, additional steps that can be taken to confirm and generalize the findings are described.

5.2.1 Attaining Realistic Monetary Estimates for the B/C Ratio

Conservative monetary equivalents were employed in estimating the B/C ratio for the operations of the H.E.L.P. program along a stretch of I-287. These estimates were based on information provided in the literature. Additional effort is required to more accurately quantify the monetary equivalent conversion rate. For example, information pertaining to passenger occupancy, driver hourly salaries, vehicle composition, loss of income for commercial vehicle drivers as a consequence of delay, local fuel costs, and the cost of typical incidents involving a collision is needed.

Additional savings may also be realized that were not considered in this study. For example, by avoiding secondary incidents, costly lawsuits may be avoided. Moreover, drivers of disabled vehicles or vehicles involved in a collision may not need to pay for towing and savings may be incurred by local police agencies, where the H.E.L.P. vehicles are able to respond to incidents in place of troopers. Additionally, the troopers can spend their time on more urgent business for which they were trained. Such factors require additional study.

5.2.2 Time-Saving Technique for B/C Ratio Estimation

A rather intense simulation approach was employed in this study in quantifying the benefits of the H.E.L.P. program and the ultimate B/C ratio. This approach required enormous simulation run time. For example, to estimate travel delay and fuel consumption resulting from 693 incidents with response from the H.E.L.P. program arising along I-287 during the six month study period, more than 41,850 simulation hours were needed and 20,790 simulation output files required evaluation. While the approach applied within this study can be directly extended for use in studying any roadway for which the necessary data is available, a less computationally burdensome technique can be created. Such a technique would not only require significantly reduced effort, but would also permit study of much larger roadway segments or networks.

Initial steps were taken to develop preliminary concepts for such an efficient technique. It is envisioned that this technique would involve the generation of a representative sample of random incidents. Such a random incident generation technique would require the fitting of probability distributions for use in random variate generation. Adequate treatment of incident distributions and prevailing traffic conditions would also be required.

Preliminary experiments were run that indicate that such an approach would be highly feasible. The results of these preliminary experiments provided nearly identical B/C ratio estimates as the procedure applied herein, employing only 600 (instead of 41,850) simulation runs.

Further investigation is required to complete the development of such a procedure and for validation.

5.2.3 Converting Impact of Incident Reduction on Traffic Characteristics to Savings in Secondary Incidents

The proposed SBSIF method has been shown to reliably identify secondary incidents from archived incident data for a given roadway segment. However, to estimate secondary incidents that did not occur as a consequence of a FSP program, one can only forecast the number of incidents that would have occurred if the program had not led to savings in travel delay or other traffic measures. This study proposed a linear relation between total travel delay and number of secondary incidents. While both sensible and practical, such a relationship has not been validated. Further study is required to validate this relationship or to identify more pertinent traffic measures that can be used for secondary incident reduction estimation. To support this, additional samples of primary-secondary incident pairs from incident data archives are required. All secondary incident data collected to date are associated with only a single roadway geometry. Thus, additional data is required for roadway segments with varying geometry and traffic conditions.

5.2.4 Standardizing FSP Benefit Estimation

One will note great variety in values resulting from FSP program B/C ratio estimation efforts conducted nationwide over past years. In fact, Latoski et al. (1999) report that such B/C ratio estimates range from 2-to-1 to 36-to-1. These prior studies have employed a wide range of estimation techniques and monetary equivalent conversion factors. Such a range of estimates makes it difficult to defend any estimate. Moreover, one cannot compare B/C estimates across programs to determine whether or not a particular program could be improved. Thus, a simple methodology that can be equitably employed across the I-95 corridor or even nationwide is essential.

A number of different approaches might be employed to develop such a standard approach. One could, for example, employ the techniques applied herein over a range of roadway geometries under varying prevailing traffic conditions and incident properties to create a set of tables of travel delay and fuel consumption savings estimates. This approach would enable any FSP program to immediately estimate travel delay and fuel consumption savings for their given circumstances.

It is also possible to estimate benefits on a per mile (or similar) basis by roadway classification, prevailing traffic conditions and incident characteristics. While less accurate than direct use of the tables, such estimates could provide very quick, back-of-the-envelope B/C approximations.

Alternatively, a standardized approach requiring more significant effort on the part of individual FSP programs could be created based on concepts described within this study and the potential next steps. Such a procedure is outlined in the flow chart of Figure 5.1.

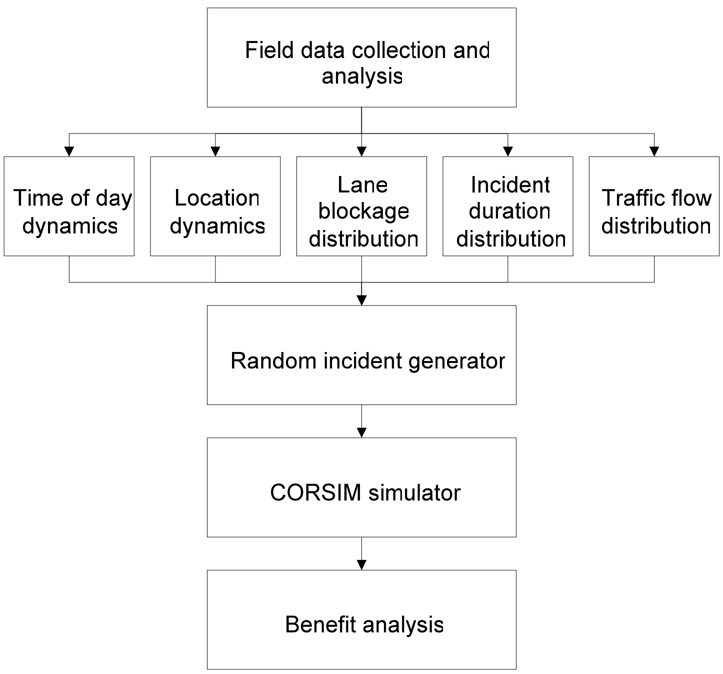

Figure 5.1 Standard B/C ratio evaluation process

This standardized procedure would create consistency in B/C ratio estimation for FSP programs. Note that the procedure as envisioned would employ the incident sampling technique described in 5.2.2. Resulting travel delay and fuel consumption estimates would be directly entered into a set of tables (similar to those developed in Chapter 4), which would then directly compute the B/C ratio using agreed upon monetary equivalent factors.

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APPENDIX A

Volume detector location and available days of the report

Detector Id	Mile Marker	Length
East 1:4575293	NYST S MP 14.2 to I-287 E Exit 4 (MP 1.8)	26083
East 2:4575295	I-287 E Exit 4 (MP 1.8) to Exit 9 (MP 7.0)	27034
East 3:4575296	I-287 E Exit 9 (MP 7.0) to Exit 11 (MP 10.8)	17213
West 1:4575289	I-287 W Exit 11 (MP 10.8) to Exit 9 (MP 7.0)	17213
West 2:4575290	I-287 W Exit 9 (MP 7.0) to Exit 4 (MP 1.8)	27034
West 3:4575291	I-287 W Exit 4 (MP 1.8) to NYST N MP 13.1	19378

Detector		weekday	weekend
East 1: 4575293	Jan	2.4.11.16.17.18.19.22	6.20.21
	Feb	21	-
	Mar	1.7.8.13.22.23	11
	April	5.6.10.	7
	May	-	-
	June	-	23.24.30
E2: 4575295	Jan	2.3.4.5.8.9.11.15.16.17. 18.19.22.25.30.31	6.13.20.21
	Feb	6.7.8.9.12.13.14.19.20. 21.22.23.26.27	10.11.17.18.24.25
	Mar	1.2.6.7.8.13.14.16.19.20. 21.22.26.27.28.29.30.	10.11.17.25.
	April	3.4.5.6.9.10.12.13.16.17. 18.19.20.25.26.27.30	1.7.8.14.15.28.29
	May	2.3.4.7.9.10.11.14.15.16. 17.21.23.24.28.29.30.31	5.12.19.20.27
	June	1.4.5.6.7.8.11.12.14.15. 25.26	2.3.9.10.16.17.23. 24.30
E3: 4575296	Jan	2.3.4.5.8.9.11.15.16.17. 18.19.22.25.30.31	6.20.21
	Feb	6.7.8.9.12.13.14.19.20.21. 22.23.26.27	10.11.17.18.24.25.
	Mar	1.2.5.6.7.8.13.14.19.20.21. 22.	10.11.17.25
	April	4.5.6.9.10.12.13.16.17.18. 19.20.25.26.27.	7.8.14.15.28.29
	May	2.3.4.7.9.10.11.14.15.16.17. 21.23.24.29.30.31	5.12.13.19.20.27
	June	1.4.5.6.7.8.11.12.14.15. 25.26	2.3.9.10.16.17.23. 24.30

APPENDIX B

Pseudocode for Simulation Replication

```
Set I_i(b,v,d_j,r_k)
For Incident I_i,  i = 1 to 693
        Replicate lane blockage properties,  b
        Replicate volume properties,  v
        Replicate incident duration,  d_j,   j = 1 to 6
        (1 for base case, 2 to 6 for duration extension cases (5 to 25 minutes))
      For incident duration case   j = 1 to 6
            Replicate incident duration,  d_j
            For random seed case  k = 1 to 5
                 Run CORSIM with  I_i(b,v,d_j,r_k)
            Next random seed,  k
      Next incident duration case,   j
Next incident case,  i
```