ABSTRACT

Title of thesis: METHODOLOGY TO QUANTIFY THE COST
EFFECTIVENESS OF FREEWAY SERVICE PATROLS
PROGRAMS. CASE STUDY – H.E.L.P. PROGRAM.

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Cost effectiveness of Freeway Service Patrol aims to construct a relationship between program operational characteristics, traffic conditions, and incident distribution. Due to existent interdependencies, benefits induced by implementing this low-cost strategy are hard to isolate and quantify. This thesis designs a methodology to accommodate variability of prevailing traffic conditions by means of micro-simulation. Its literature review presents main ramifications of incident related research, exploring operational aspects related to emergency response, non-recurrent congestion estimation and micro-simulation procedures. A CORSIM model is developed to account for incidents development, provide relevant output (i.e., delay, fuel consumption, emissions and occupancy values), and estimate a panel of benefit-cost ratios. Also, based on the feasible area created by shock waves a new procedure to determine the number of secondary incidents is developed. Compared with similar research, the current research provides relevant results in terms of warranted traffic conditions for freeway service patrols deployment.

METHODOLOGY TO QUANTIFY THE COST EFFECTIVNESS OF FREEWAY SERVICE PATROLS PROGRAMS. CASE STUDY – H.E.L.P. PROGRAM

By

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Chapter 1. **INTRODUCTION**

1.1. Motivation

Regardless of congestion type (recurrent or non-recurrent), national statistics are not encouraging, and show that over the past two decades traffic conditions on urban freeways, particularly for peak commuting hours, have deteriorated at a rapid rate. The reality is that the urban sprawl combined with the relative scarcity of mass transit alternatives continues to induce more demand for automobile as a primary mode for commuting. For example, previous studies have estimated that although urban freeways represent only three percent of the total roadway mileage, they account for 31 percent of the total vehicles-miles traveled (Lindley, 1987). Furthermore, the high usage of urban freeways combined with the increase of traffic volumes, has generated a drastic deterioration of travel time and speed values. Cragg and Demetsky (1995) report a significant inflation of the peak hour traffic percentage (defined as having speeds lower then 35 mph) from 40 percent in 1975 to almost 80 percent in 1990.

This degradation of mobility function for urban freeways has multiple negative social and economical implications on our every-day driving experience. While the majority of negative effects have been attributed to increases in delay and fuel consumption (U.S. Department of Transportation, 1997a), less quantifiable aspects such as pollution and secondary incidents, and decrease in safety and personal time are equally important. Moreover, while for recurrent congestion, the negative effects are predictable in magnitude and location, for non-recurrent congestion this is hardly the case due to inherent volatility of driver behavior. Still, while unpredictable in nature, the negative effects of incidents can be efficiently mitigated either by means of swift reaction (i.e., response and clearance time reduction) or by means of control of traffic flow characteristics (ramp metering, rerouting, variable message signs (VMS)). All these methods are comprehensively identified by the Incident Management (IM) procedures, formally defined as “the systematic, planned and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of incidents, and improve the safety of the motorists, crash victims, and incident responders” (P.B. Farradyne, 2000).

One of the key components of any incident management program is defined by the Freeway Service Patrols (FSP). Ever since FSP first implementation, in 1960’s, they propagated as one of the most popular low-cost strategies to alleviate the negative effects of incidents in urban areas. Their functionality practically extended to every stage of an incident situation and, if deployed correctly resulted in significant savings in delay, fuel consumption, secondary crashes and pollutant emission rates. Although the effectiveness of FSP is not questionable with benefit to cost ratios ranging from 2:1 to 32:1 (Fenno and Ogden, 1998) there has been relatively little research on how sensitive the cost-effectiveness of FSP is to the variability of prevailing traffic conditions, the spatial and temporal distribution of incidents, and the operational characteristics of the fleet.

FSP cost-effectiveness studies focused on estimating program benefits as differences of highway system performance when “with” and “without” or “before” and “after” FSP operations are considered. Moreover, majority of studies were designed to address program specific objectives and to efficiently exploit the available data. As a result, FSP's cost-effectiveness research is far from being standardized with deterministic queuing theory, customized macroscopic models, and comparison of "before" and "after" real world data[1] all used as viable alternatives to determine the impact of freeway service patrols operations on highway performance.

The extent in which a method replicates the "true" value added by Freeway Service Patrols operations largely depends on validation procedures and method flexibility to replicate different aspects of a highway environment. Deterministic queuing theory is by far the most schematized approach as a representation of FSP operations, with the interaction between vehicles ignored and flow characteristics fragmented over time and space. An improved power of representation is achieved by macroscopic simulation, with flow characteristics considered as a continuous rather then fragmented input. Finally, provided that extensive calibration and validation procedures are implemented, microsimulation has the highest power of representation, with both interaction between vehicles and continuous representation of flow characteristics considered.

The current methodology of estimating Freeway Service Patrols cost-effectiveness is unique in the desire to better understand and represent the complex interactions within incident situations at a microscopic level considering variability of prevailing traffic conditions. Different scenarios describing freeway service patrols operations for a highway having 65 mph free-flow speed and a Level of Service (LOS) B, C, and D are analyzed in terms of the B/C ratios. Applicability of results for

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[1] California DOT FSP – estimates difference in average travel speeds under normal and incident conditions making extensive use of probe vehicles and loop detector data

practitioners is supported by the correspondence between the LOS, incident capacity reduction and microsimulation parameters describing incident conditions (rubberneck factor, car following sensitivity factor, and traffic volumes).

1.2. Scope for Research

The cost-effectiveness of freeway service patrols depends on the operational characteristics of the fleet of patrol vehicles, the spatial and temporal distribution of incidents and, the variability of traffic prevailing conditions. While prior research has detailed the cost effectiveness of FSP's considering the impact of different fleet characteristics (Pal, 1999) or incident spatial and temporal characteristics (Garib et al, 1997) there is a relative scarcity relative to the impact of different prevailing traffic conditions.

Still, in analyzing the cost-efficiency of FSP's deployment on urban freeway networks, prevailing traffic conditions are probably one of the most important factors to be considered. Indeed, the cost-efficiency of FSP's will largely depend on the way in which the incident time reduction, achieved by means of swift response of service patrols, transfers into a significant impact in terms of further traffic conditions developments. The scope of current study is to address those circumstances of traffic conditions in which the incident time reduction achieved by FSP's service results in delay, fuel consumption and secondary incidents savings such that the cost-efficiency of FSP program is guaranteed.

For the purpose of the current study, incidents and freeway service patrol fleet characteristics are described by the Highway Emergency Local Patrols H.E.L.P. available data set (I-287 study area). Furthermore, in addressing the impact of variability of incident traffic conditions on the cost-efficiency of FSP patrol three main parameters are considered: traffic volume, incident capacity reduction (which define the level of demand and the impact of an incident on it), and car following sensitivity (which captures driver's propensity to adjust to incidents). A CORSIM simulation model is defined to account for H.E.L.P. incident characteristics, prevailing traffic conditions and different levels of total incident time reduction. Finally, simulation outputs in terms of delay, fuel consumption, emissions and mean occupancy rates are used to define the benefit cost ratio of the program and indicate the H.E.L.P. cost-efficiency boundaries.

1.3. Research Objectives

In order to determine the cost effectiveness of FSP's using micro-simulation the current study pursues several research objectives:

(1) Evaluate characteristics of a pilot project using descriptive statistics and compare results to national statistics;

(2) Provide a comprehensive overview of the freeway service patrols related state of research;

(3) Design a micro-simulation model capable of replicating the incident evolution in different traffic conditions and provide the desired output in terms of delay, fuel consumption, emissions and mean occupancy rate values;

(4) Describe the boundaries of the sensitivity analysis for each of the parameters considered and their applicability in the national context;

(5) Formulate and test a procedure to account for the probability of secondary incidents based on the existence of a shock wave. Assess the relation between the number of secondary incidents and the shape of the feasible area;

(6) Analyze the results and indicate future directions of research.

1.4. Organization and Summary

The dissertation includes six chapters. Chapter 2 provides a literature review on the relevant aspects of freeway service patrol operations. First, emergency response is detailed as a representation of operational aspects related to routing characteristics, fleet and facility locations. Second, an overview of key evaluation methods for non-recurrent congestion and incident detection is presented. Third, characteristics and evaluation metrics of some of the most representative FSP's programs are presented. Finally, prior traffic studies relevant to the area of incident modeling which used CORridor SIMulation (CORSIM) as a primary simulation package are referenced.

Chapter 3 presents a general overview of the Highway Emergency Local Patrols (H.E.L.P.) and assesses the performance of the program using descriptive statistics. These performance measures include the spatial and temporal distributions of the incidents, the incident response and clearance times by time of the day and day of week and the frequency of secondary incidents. In order to understand how the H.E.L.P. program differs from other programs results are compared to national values.

Chapter 4 defines the research methodology, addressing the input preprocessing, computational efficiency and output aggregation. The input generation is analyzed from the perspective of the main sensitivity analysis parameters and bounds are proposed for implementation. Computational effort and model convergence is used to motivate the number of multiple runs. The output procedure is detailed for the secondary incidents dissemination and a new methodology based on shock waves is proposed.

Chapter 5 discuss the relevance of microsimulation parameters bounds in the context of H.E.L.P. operating conditions and propose equivalent measures for practitioners.

Chapter 6 formulates a procedure to determine a feasible area for the secondary incidents occurrence based on the output provided by microsimulation in terms of mean occupancy rates.

Chapter 7 presents the results obtained with the designed methodology in terms of delay, fuel consumption, emissions and secondary incidents reduction. According to the resulted values of the benefits and the HELP program cost structure for each of the sensitivity analysis scenarios a benefit-cost ratio is computed.

Conclusions and further directions of research are presented in Chapter 8.

Chapter 2. **LITERATURE REVIEW**

2.1. Introduction

Over the past two decades, with the advent of ITS technologies, there has been a tremendous progress in the way in which traffic informational flow is analyzed and managed. Indeed, incident management has been one of the early beneficiaries of new ITS technologies that have led to shorter incident detection and response times, better communication and control channels, and better means for forecasting the magnitude and frequency of negative events.

While these strategic objectives of incident management programs are the same across different traffic conditions, the efficiency of each program is ultimately dictated by the way in which different strategies are selected and tailored to represent specific operational needs. As a low-cost method to address incidents, freeway service patrols have reached such a popularity level that their efficiency seems to be beyond any doubt.

The following paragraphs are to be interpreted as an overview of the most relevant areas with respect to the freeway service patrol research. The first section defines the general background by presenting the emergency response literature from the operational point of view with specific emphasis on facility location and routing studies. The second section describes of incident-related evaluation methods and their applicability in different freeway service patrol studies around the United States. Finally, since the current research makes extensive use of micro-simulation, the third section is dedicated to CORSIM or TSIS 5.1 model with an overview of the platform main capabilities and limitations. The last section concludes the literature review by summarizing the current research state in the domain of FSP evaluation.

2.2. Emergency Response Research

Within the operation research community emergency response is one of the most explored areas. The majority of studies address the hub oriented applications of the emergency services (such as those for hospitals or fire-companies). In this area one of the main objectives of emergency service providers is to locate the facilities and equipment to maximize coverage, or the set of emergency locations such that they can be reached within a specific response time.

In one of the earliest studies Toregas et. al. (1971) formulated the emergency facility location as an Integer Programming (IP) set-covering problem slightly modified to address violations of integrality. In the same direction, Fitzsimmons (1973) proposed an analytical formulation in which the variability in ambulance placement is considered by means of an optimum-seeking computer search routine[2]. His study considered the system mean response time as a measure of effectiveness and the emergency response mechanism represented by the conditional probability p(j) of a certain system state occurring (having “j” busy ambulances).

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[2] “Search Routine directs changes in the ambulance locations with the objective of progressively decreasing the system’s mean response time”

Recognizing that reallocation costs are a representative part of the location problem, Plane and Hendrick (1977) proposed a modified version of the set-covering formulation for fire companies, in which existent facilities location is considered by means of a hierarchical objective function (“first the a number of necessary stations to satisfy the response constraint is found and then the number of available stations is maximized“). It is important to note that a multi-actor decisional process was achieved via the involvement of fire chiefs in the analysis. Further refinements are considered by Schilling et. al. (1979) in which multiple problems are formulated based on the maximum covering concept to account for tandem (primary and secondary) equipment allocation, tandem multi-objective equipment allocation and generalized equipment and facility allocation (fleet).

The main drawback of both set covering and maximum cover formulations is represented by the deterministic frame in which the probability that an arriving demand will be not serviced during the busy period is not considered. The transition from this oversimplified format was realized by Daskin (1983) in which a maximum expected covering location problem (MECLP) is formulated to account for the probability of failure in meeting the demand from a specific facility. His research proved that the proposed objective function has a multi-dimensional format and that the generated set of non-inferior solutions is highly sensitive to the probability of failure.

For an even more stochastic oriented approach on the emergency facility location the works of ReVelle and Hogan (1989) and of Ball and Lin (1993) are referenced. Their research used as starting point the Maximum Covering Location

Model (MCLM) formulated by Daskin and added reliability constraints on the demand points. The fundamental difference between the two studies is the way in which the busy fraction of emergency vehicles is modeled: estimation (ReVelle and Hogan) and randomly induced (Ball and Lin).

In terms of the emergency routing characteristics**,** Bertsimas and Van Ryan (1993) provide one of the most comprehensive models. Assuming a stochastic and dynamic environment and using the classical traveling repairman problem, they seek to optimize the response of the system by minimizing the average system time (waiting and on-site service). Several scenarios are detailed as different "traffic conditions" (demand characteristics) and vehicle capacity characteristics are considered. Two of their key findings are that in the case of capacitated vehicles, the system geometry and the depot location have a strong influence on the stability condition, and, that the characteristics of demand will have a high impact on the classical queuing behavior. The impact of the traffic conditions is schematized using a sensitivity analysis of the system time with respect to the travel cost.

Although intuitively an accurate emergency response evaluation results from simultaneously considering the demand distribution, the characteristics of the fleet and the prevailing traffic conditions their inherent variability increases the complexity of the problem tremendously. In that perspective, all of the emergency response studies presented so far have schematized the interaction of emergency vehicles with the traffic prevailing conditions.

If this simplification is not representative for hub oriented emergency services (such as fire-companies or hospitals), in the case of roving or patrolling services such as freeway service patrols it has a great impact. Due to the specific structure of this service the main objective of an optimization procedure should be directed towards the minimization of drivers total time rather then the response time of emergency vehicles. In that context, using a customized macroscopic simulation model with route diversion capabilities, Pal and Sinha (2002) explore the impact of the traffic conditions on the quality of incident response. In contrast with the classical minimization of the waiting time or system time, their approach considers the total vehicle hours in the system as the main measure of effectiveness.

2.3. Freeway Service Patrols Studies

In spite of their differences, all incident management strategies try to influence the same parameters of incident development. Considering the ill-predictable character of incidents in terms of spatial and temporal patterns, and the fact that the resulted capacity reduction will be a measure of the behavioral composition of the traffic mix, road conditions and weather conditions, incident management defines as primary control variables ***the traffic flows*** and ***the total incident time duration***.

As one of the earliest and most popular incident management strategies, Freeway Service Patrols (FSP) programs have been subject to a relative high degree of attention within the transportation research community. Section 2.3.1 provides a short introduction to the general background, referencing the methodologies used to address incident related effects while Section 2.3.2 identifies the characteristics of the main FSP evaluation studies conducted in United States.

2.3.1.Estimating Non-Recurrent Congestion – General Background

Messer et al. (1973) and, Morales (1986) propose analytical methods to describe the evolution over time of a specific incident. While the first study applies the Lithhill and Whitham shock wave theory to predict the travel time in incident conditions, the later uses the queuing theory representation of the demand flow with respect to the incident flow to graphically determine the corresponding delay. Both approaches are deterministic in that they assume incident development is known *a-priori* either by means of off-line or real-time estimation.

The majority of latter studies have acknowledged the stochastic nature of traffic incidents by incorporating measures to account for variability in incident duration, demand rate and capacity reduction. Garib et al. (1997) provides a comprehensive review of the most relevant research related to these three main factors. Also in terms of incident effects estimators the majority of studies have used delay as the most pertinent representation (Al Deek et al. 1995; Garib et al. 1997; Sullivan 1997).

2.3.2.Freeway Service Patrols Programs in United States

As one of the earliest and most popular incident management strategies, Freeway Service Patrols (FSP) programs focus on mitigating the negative effects of incidents, reducing the total incident time by means of rapid response and clearance. Due to their popularity as a low-cost incident management strategy, FSP's have generated a high degree of attention within the transportation research community. Still, with the notable exception of Pal study (1999) all FSP research has been conducted to specifically address program's local characteristics.

Early evaluation efforts of freeway service patrols efficiency were directed towards quantifying negative effects of congestion by means of simple analytical procedures. Using the Highway Performance Monitoring System (HPMS) to reflect the accident characteristics and, volume profiles to represent the traffic prevailing conditions, Lindley (1987) develops an empirical based procedure to evaluate the urban freeway congestion at the national level. In his study, incident effects measured in terms of delay and fuel consumption for the year 1987 were estimated at 766.8 millions vehicle-hours and 845.9 millions gallons respectively. Also, these values were expected to reach values approximately six times higher in 2005.

As a primary source of information on the number and characteristics of Freeway Service Patrol (FSP) programs, Fenno and Ogden (1998) provide a comprehensive overview of the state of practice at a nationwide level. Based on a telephone survey with the managers of 53 freeway service patrols across 22 states, the study reports a high degree of reliability of the programs with benefit-cost ratios ranging from 2:1 to 36:1. However, presented results are restrained to specific assumptions of each study and should not be used to define any comparison base.

The difficulty in defining a general methodology to analyze the efficiency of freeway service patrols programs has been addressed by Morris and Lee survey (1994) in which public perception, safety benefits, operating characteristics, congestion delay, air quality, energy consumption benefits, and benefit-cost ratios are all identified as possible measures of effectiveness. Due to this wide range of measures of effectiveness in the context of complex incident management programs, evaluation studies and methods have difficulties of isolating the specific benefits of freeway service patrols. The authors indicate that the “appropriate” combination will be described by the systematic analysis of the characteristics of the programs and the specific policy objectives.

Early evaluation efforts of freeway service patrols cost-efficiency quantified the negative effects of congestion by means of simple analytical procedures. Using the Highway Performance Monitoring System (HPMS) to reflect the accident characteristics and volume profiles to represent the traffic prevailing conditions, Lindley (1987) develops an empirical based procedure to evaluate the urban freeway congestion at the national level. In his study, incident effects measured in terms of delay and fuel consumption for the year 1987 were estimated at 766.8 millions vehicle-hours and 845.9 millions gallons respectively. Also, these values were expected to reach values approximately six times higher in 2005.

Consistent with the dramatic increase in urban congestion, FSP programs and corresponding evaluation methods have increased exponentially over the past two decades. The most successful programs evolved in the highly urbanized areas with well defined ITS architecture (California FSP; Washington State Patrol; CHART Emergency Traffic Patrols). For an annotated bibliography on the Benefit/Cost Studies of Freeway Service Patrols identifying study strengths and weaknesses Minnesota Department of Transportation FIRST program evaluation (2004) provides a good reference.

Probably one of the largest and more successful programs in the United States is the **California FSP,** jointly administrated by California Department of Transportation (CalTrans), California Highway Patrol (CHP), and local planning agencies. These agencies evaluation efforts were conducted from a comprehensive point of view, and considered the incident development both “before” and “after” program deployment for a ten-mile stretch of highway on Interstate 880.

In terms of data availability more than 276 hours of field data (loop detector, probe vehicles and incident logs) were collected to comprehensively represent the freeway operating conditions at the considered site (Petty et al., 1996). Without considering the effects of secondary crashes, fuel consumption or emissions the benefit cost ratio for an **average reduction of incident duration of 15 minutes is reported to be 5:1** (Skabardonis et al. 1998). One interesting observation regarding the efficiency of FSP operations is related to the existence of an over-sampling bias for the short term incidents. The study points out that the increase in the number of assisted breakdowns is a misleading efficiency measure, as roving trucks might stop to assist each and every motorist regardless of their actual need for help.

Using similar data sources to the California FSP study, Giuliano et al. (2004) propose a methodology to estimate the secondary accident rates on Los Angeles freeways. Based on the existence of favorable conditions (within a queue formation or at the boundary determined by the shock wave) secondary incidents are identified using a stratified search procedure. While the primary incident data consisted in more than 80 thousands records, their filtering procedure identified 177 potential secondary accidents which resulted in a rate of **0.007 for each reported incident**.

Another well documented program is represented by the **Hoosier Helper** administrated by the Indiana Department of Transportation. In this case, the Borman Expressway representing a 16 mile stretch of the six-lane Interstate 80-94 was used as a test case. In contrast with the case specific evaluation method of California FSP, the current research developed a systematic and comprehensive framework which can be further used in improving the efficiency of existing programs and optimally designing new ones (Pal, 1999). The replication of the complex interaction between the incident distributions, operational characteristics of rowing patrols and traffic prevailing conditions was facilitated by the design of a macroscopic simulation model “XXEXQ” (Pal and Sinha, 2002).

General optimality in freeway service patrols assignment was achieved applying a nested partition algorithm in which the feasible region was defined by the set of all possible seeds (starting points) combinations for the beats (partitions). Within the partition workloads, defined as the total clearance time to address the incidents, a local search was conducted with the feasibility region restrained to the bounds imposed by the operating time (Pal, 1999).

In terms of the cost-effectiveness of the program, the same benefit-cost ratios method was used. The program cost structure had a rather fixed format and it was evaluated by aggregating the equivalent annual investment cost, employee salaries and benefits, overhead cost and, maintenance cost. The benefit structure, on the other hand, was designed to vary with respect to the incident generation mechanism, estimation of the unit travel time value and characteristics of the incident simulation. Using delay savings, secondary crash reduction and vehicle operating savings as the main evaluation parameters, the reported benefit-cost ratio was **4.71:1 for the daytime program operation** (6:00 a.m. to 8:30 p.m.) and **13.28:1 for the 24 hour program operation** (Latoski et al., 1999). Still, the increase of B/C ratios for daytime operations when compared with the 24 hour operations is questionable, considering that majority of incidents happen in the peak hours (e.g., non-recurrent delay increase for 24 hours operating conditions is reported to be more then double).

Network wide estimation of FSP efficiency over an entire year is documented by the Coordinated Highway Action Response Team (**CHART)** incident management program. The program, implemented in both the Washington D.C. and Baltimore Metropolitan Areas, was designed as a combination of Emergency Traffic Patrols (ETP) and Emergency Response Units (ERU). While the ETP units are responsible for assisting motorists with disabled vehicles, the ERU units act as mobile traffic control facilitators at the incident site (Chang and Point-Du-Jour, 1998).

Compared with the California FSP and Hoosier Helper methodologies, the program reports are more statistically oriented with program efficiency reflected through a “with” and “without” analysis facilitated by the CORSIM (TSIS) microscopic simulation model. The benefits of CHART incident management program resulted in a total delay time reduction of **23.36 million vehicle-hours**, a total fuel consumption reduction of approximately **8.6 million gallons** and a contribution to a potential reduction of **1344 secondary incidents** (Chang and Point-Du-Jour, 2001).

Finally, it is important to note that with the explosive increase of freeway service patrols programs around United States, a significant amount of research has been conducted to evaluate their effectiveness (Dutta et al. 1997; Cuciti and Janson, 1995; Georgia DOT, 1996; Texas DOT, 1997; Hawkins 1993).

2.4. CORSIM (TSIS 5.1) Simulation Package

CORSIM (TSIS 5.1.) or Traffic Software Integrated Systems was developed to provide a user friendly interface for the microscopic integrated simulation models of NETSIM (arterial) and FRESIM (freeway). Combined with a graphical network editor (TRAFED), a Visual Basic customized script engine and a visualization tool (TRAFVU) it represents one of the most powerful and comprehensive micro-simulation platform to date.

Over the past 30 years with the support of Federal Highway Administration, the platform has been extensively refined and at this point uses widely recognized and validated car-following and lane-changing mechanism. Previous studies show that in terms of replicating the freeway operations such as ramp metering, weaving, work zones or incidents CORSIM rates as one of the leading simulation packages (Skabardonis,1999), although several amendments are to be made.

Since capacity of the road is not an explicit input in CORSIM, its calibration can be tedious as a large number of default parameters need to be changed to accurately replicate the real conditions. For non-incident conditions, a fair representation can be obtained by using the car following sensitivity factor (Payne et al., 1997; Halati et al. 1997). For the incident or bottleneck capacity however, the calibration proves to be more difficult and several researchers have recommended the alternative of a sensitivity analysis. The complexity of the analysis will be dependent on the characteristics of the significant parameters considered: rubberneck factor and car-following sensitivity factor (Payne et al, 1997); jam density, free flow speed and jam headway (Crowther, 2001) or even minor changes such as the random seeds (Hall et. al, 2000).

With respect to the microscopic behavioral mechanisms such as lane-changing, car-following and gap acceptance in bottleneck conditions, the research of Wang et al. (1999) tries to calibrate CORSIM by minimizing the squared error between the field delay and simulation delay. The authors conclude that even a comprehensive calibration mechanism will not always reflect the classical macroscopic speed-volume relations of traffic streams (Crowther, 2001).

In terms of transient behavior Crowther (2001) analyzes the impact of car-following logic using performance measures of speed, delay, and travel time in under-saturated, saturated and over-saturated traffic conditions. The CORSIM default analytical formulation of car following mechanism (Pittsburgh) is used as a benchmark in verifying the results. Using a uniform arrival distribution and minimizing the effect of lane-changing mechanism, the author indicates that in under-saturated and over-saturated conditions the simulation results are consistent with the general analytical formulation. However, the model seems to exhibit large deviations for the saturated conditions, with the “aggressiveness” in accelerating and decelerating rates manifested in higher speeds then the free flow value and queue formation respectively.

The capacity to reflect the changes in the geometric design and to model junctions has been explored by Ulerio (1996). His research is indicative in that the accuracy of CORSIM representation is limited to isolated junctions and that a major source of insensitivity is the lane changing logic.

Since micro-simulation can be costly in terms of computational effort**,** Rahti and Nemeth (1985) recommend the use of common random numbers (CRN) and antithetic variates (AV) as effective variance reduction methods.

Bloomberg and Dale (1999) have suggested that the prior “know-how” of simulation models plays an important role, as minor changes to the input parameters can result in large variation in the results. Also, they recommended the use of multiple simulation programs and different measures of effectiveness for a higher confidence on the results.

2.5. Conclusions

In the general framework of incident management, results of previous freeway service patrols research indicate the need for further exploration of system interdependencies. It is important to highlight that the evaluation measures will be highly dependent on the way operational aspects, demand distribution of incident response and traffic conditions are simultaneously considered. If the general trend is without a doubt towards the aggregation of these three main factors, due to the inherent complexities at hand most of the studies so far have only considered a limited framework.

From the operational point of view, and with a few exceptions, previous studies have been oriented towards the location of emergency facilities and the routing of emergency vehicles for which the interaction with the traffic conditions was highly schematized. At the same time, the demand side was generally described by a non-homogenous Poisson process which seemed to give a close approximation on the way incidents are generated.

Within an incident scenario, the analysis of prevailing traffic conditions has considered the reduction in capacity, the fluctuations in demand, and the characteristics of incidents as the main parameters to influence the system performance. In these studies delay and incident duration are the most representative measures of effectiveness.

Although, due to their relative low-cost, FSP's programs had become an increasingly popular option in the incident management programs of state agencies, analyzing their cost effectiveness is far from a standardized format. As several surveys pointed out (Morris and Lee, 1994; Fenno and Ogden, 1998), in addressing the cost-efficiency of FSP programs, nation-wide there is a wide range of evaluation methods which is mainly generated by the differences between program's objectives and the difficulty of quantifying the exact impact of FSP's in the context of complex incident management programs. Nevertheless, in highly urbanized areas with well defined Intelligent Transportation Systems (ITS) architecture, the FSP's state of research has experienced a shift from the statistical interpretation of data towards more analytical or simulation oriented methodologies.

Indiana DOT Hossier Helper program has experienced probably the most complex methodology to address the cost-effectiveness evaluation of freeway service patrols. Program evaluation was facilitated by the existence of a macroscopic simulation model specifically designed to address freeway service patrols operations (XXEXQ). Still when considering the differences between the 24 hours operation program and peak-hour program, some of the results in terms of the obtained benefit cost ratios are questionable. Another representative program, California DOT FSP program is the only one whose evaluation is based on comprehensive data both “before” and “after” freeway service patrols implementation. While the obtained results are extremely valuable in establishing FSP’s evaluation benchmarks, the entire process proves to be data intensive and hard to replicate for other programs. Finally, Maryland DOT CHART program combines the capabilities of a microsimulation platform (CORSIM) with the characteristics of incident data available from police records to obtain a network wide estimation for an entire year period.

From an evaluation perspective most of the freeway service patrol studies use the benefit-cost ratio as the most common method to evaluate the program performance. The cost structure will be generally described by the aggregation of the equivalent annual investment cost, employee salaries and benefits, overhead cost and, maintenance cost. The benefit structure on the other will be subject to data availability either “before and after” or “with and without” methods being used.

Finally, depending on the desired level of accuracy desired and the input data requirements, the complexity of the evaluation procedure can be adjusted to the specific program needs. Therefore, descriptive statistics, analytical methods, or simulations are all valid procedures for modeling and evaluating the performance of freeway service patrols.

Chapter 3. **H.E.L.P. PROGRAM CHARACTERISTICS**

3.1. Highway Emergency Local Patrol Program Description

Hudson Valley Emergency Local Patrol (H.E.L.P.) program is operated by the New York State Department of Transportation and managed and supervised by New York State Police assigned to the Hudson Valley Transportation Management Center. Since the program highway patrol areas have a multi-jurisdictional character, the existence of a strategic partnership between these agencies and the New York State Thruway Authority and the Westchester County Department of Public Safety contributes to the efficient deployment of H.E.L.P services.Currently, the Hudson Valley program provides 25 vehicles over 205 centerline miles of limited access highway (Hudson Valley Transportation Management Center, 2004) (Figure 3-1).

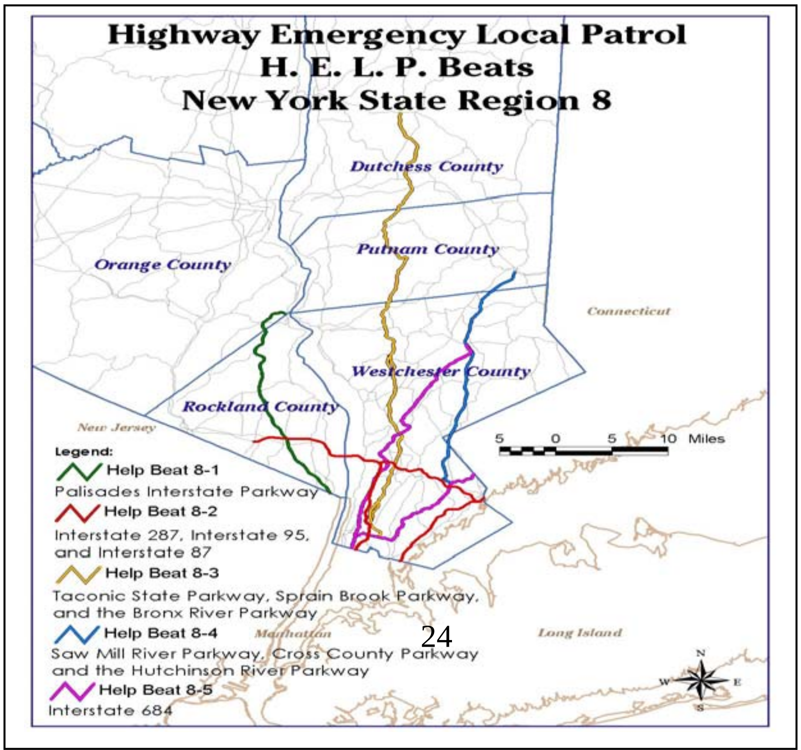


Figure 3-1 Coverage Area for the H.E.L.P. Program

The hours of operation of the H.E.L.P. trucks patrol are exclusively designed to address peak communing hours (6:00-10:00 a.m. and 3:00-7:00 p.m.) during the regular work week (Monday till Friday). Also, the service patrols are "provided through contracts with private vendors and the road service is provided to the public for free" (Hudson Valley Transportation Management Center, 2004).

The main attributions of H.E.L.P. staff/drivers are "to change a flat tire, provide gas or necessary fluids, provide jump starts and perform minor repairs for disabled motorists, thus helping to get motorists on their way in a fraction of the time it would take to dispatch a tow truck. Their responsibility also extends to clearing operations but only for motor vehicles with a gross weight of 6,000 pounds or less and/or small debris" (Hudson Valley Transportation Management Center, 2004). If necessary, H.E.L.P trucks act as a very effective on-site incident management tool, providing the law enforcement at the incident scene the proper signalization (e.g. flares, flags) or rerouting the traffic to alternative routes. To minimize the H.E.L.P impact on traffic flow and, provided that the existing conditions warrant, all the on-site operations will be executed on the shoulder.

In terms of the service quality, the main objective of the HELP program is "reaching the disabled motorists within 10 minutes of their vehicular breakdown while spending a maximum of 15 minutes in providing the necessary assistance. In order to achieve this, the HELP vehicles patrol continuously on their assigned highway segments while using designated turnaround locations" (Hudson Valley Transportation Management Center, 2004).

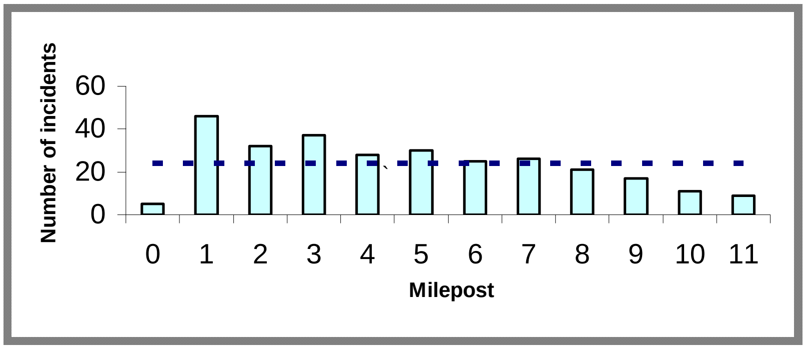
3.2. Pilot Project Overview

With a length of approximately 10 miles and part of the 8-2 Beat of H.E.L.P.'s coverage area, the I-287 study area is delimited by the I-95 Corridor on the east-bound and Tappan Zee Bridge on the west-bound. For the studied area, available incident data consisted of June 2004 incident logs compiled by the New York State Police from different sources (thruway narratives, ATMS and patrols HTE-CAD), and traffic information resulted from two sensor detectors (10.2 East and 2.7 East). Incident logs comprised a total of 346 records which were organized as an EXCEL database, each of the records having entries describing the incident time line (dispatch, arrival and cleared time), incident location and type, incident direction, type of service provided, number and types of vehicle involved, extent of the blockage, road and weather conditions and respondent unit identifier. Also, the sensor traffic data provided breakdowns of hourly counts by totals, length of vehicles and speed of vehicles.

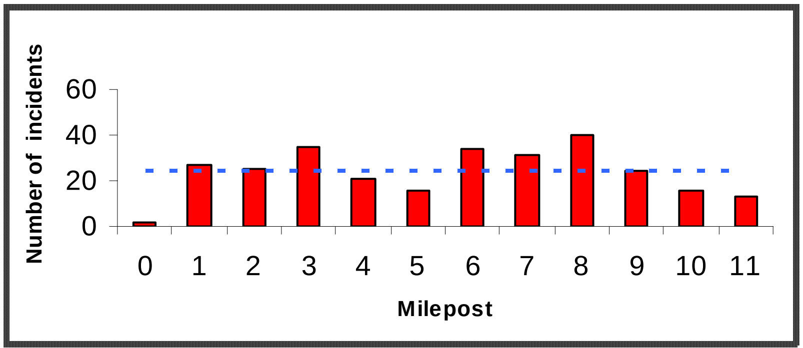
Due to its ease of use, one of the most common methods to analyze the cost-efficiency of freeway service patrols is identified by the interpretation of descriptive statistics (Dutta et al. 1997; Cuciti and Janson, 1995; Georgia DOT, 1996; Texas DOT, 1997; Hawkins 1993). However, since available data generally consists of measures of effectiveness proxies (e.g. detection time, response time) this method should only be used as a general intuition on the cost-effectiveness of the program and not as a definite answer. In the following paragraphs, descriptive statistics for H.E.L.P. study area will be presented considering the incident characteristics, the detection efficiency, the incident response and clearance times and number of secondary incidents.

3.2.1. Analysis of Incident Characteristics

The evaluation of the incident distribution characteristics plays an important role in establishing the main operational parameters of a freeway service patrol. Location in time and space of incidents, their type and the impact in terms of lane blockage are critical parameters in determining the distribution of patrol vehicles around freeway segments, assessing the impact area under the average and worst incident scenarios, and revealing the hazardous highway segments from both the safety and operations perspectives (Chang and Point-Du-Jour, 1997). The spatial distribution of incident data on east and west bound (Figure 3-2) reveals significant differences from the mean of 24 incidents per mile for both directions.



(a)



(b)

Figure 3-2 Incidents Frequency by Location: (a) east-bound (b) west-bound

With respect to the temporal distribution from the total of 346 incidents, 45% correspond to H.E.L.P. operating hours (peak period) and, 42% to off programs hours or weekends. Also, 13% of the H.E.L.P. serviced incidents having a total service time less then one minute were defined as questionable (Figure 3-3).

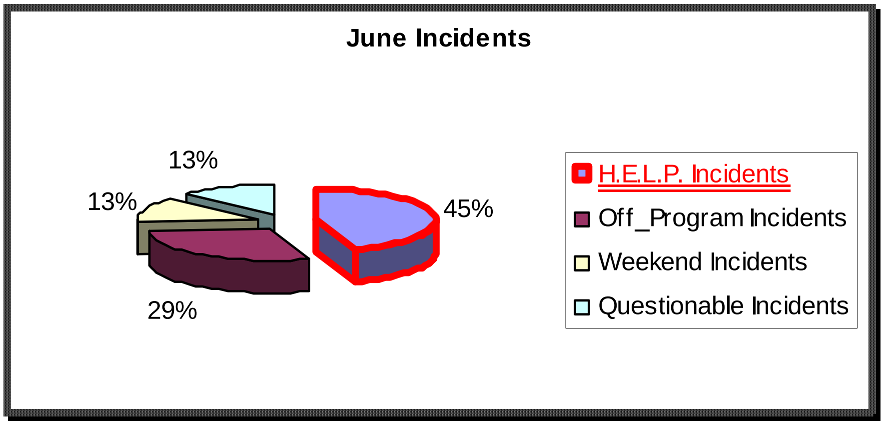


Figure 3-3 Distribution of Incidents by Peak, Off-Peak and Weekend Hours

The hourly frequency the incident data reveals a mean value of 14 incidents/hour, with morning (6:00-10:00) and afternoon (15:00-19:00) peak-hours including approximately 63% out of the total number of incidents (Figure 3-4).

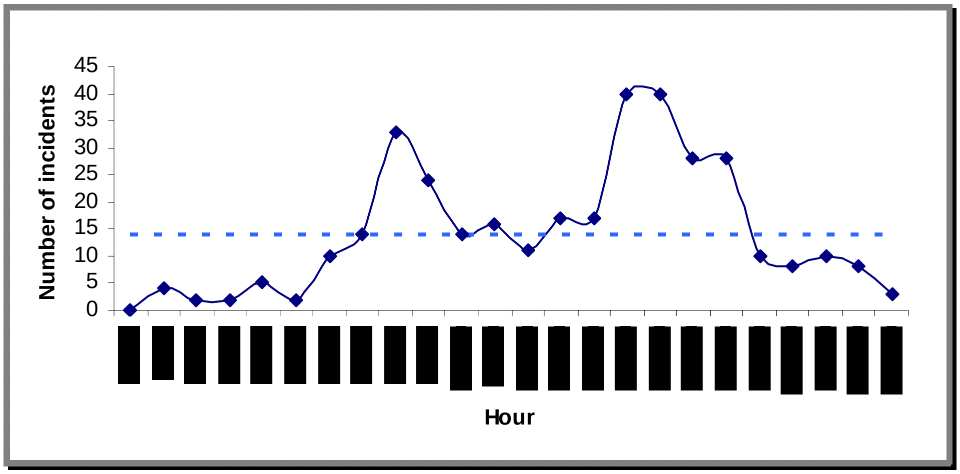


Figure 3-4 Temporal Distribution of Incidents

In order to explore incident characteristics some of the categorical variables of interest such as incident type, direction, and road condition were recoded using the following description:

- Incident type= *Inc_type* (0- Disabled Vehicle, 1- Disabled Vehicle Towed Off, 2- Disabled Vehicle Road Side, 3- Debris, 4- Accident property damage only, 5- Accident injuries)
- Extent of blockage =*No_lan_blk*
- Incident Direction= *Direction* (0 –east , 1 –west)
- Incident Location = *Milepost*
- Road Condition = *Rd_cond* (0 –dry, 1-wet)

Table 3-1 presents the mean and the standard deviation of all of the above parameters for three scenarios of interest (H.E.L.P. operating hours, after program hours and, week-end hours). Both west and east directions have almost equal numbers of incidents during the weeks, this equilibrium shifting towards west in weekends. Furthermore, only 7% to 16% out of total number of incidents have a “wet” road condition, and majority of incidents are positioned on shoulder (no blockage involved – *no_lan_blk* values close to 0). Finally, the mean of *inc_type* indicates that most of the incidents are disabled vehicles.

	H.E.L.P. PROGRAM	**AFTER PROGRAM**	**WEEKEND**
	Mean (Std_Dev)	**Mean (Std_Dev)**	**Mean (Std_Dev)**
Inc_type	1.27 (1.48)	2.01 (1.49)	1.87 (0.18)
No_lan_blk	0.02 (0.14)	0.11 (0.40)	0.00 (0.00)
Direction	0.50 (0.5)	0.48 (0.50)	0.59 (0.07)
Rd_cond	0.12 (0.32)	0.16 (0.37)	0.07 (0.04)
Count	**155**	**99**	**46**

Table 3-1 Incident Data Descriptive Statistics across Different Scenarios

Furthermore, incident type distribution reveals the impact of H.E.L.P operating hours when compared with after program and weekend hours. Due to the capacity to rapidly address disabled incidents, H.E.L.P trucks effectively mitigate the effect of abandoned vehicles (tow offs) and debris (Table 3-2).

	Inc_type					
	DV	DV_Tow Off	DV_Road_Side	Debris	AA_PDO	AA_PI
H.E.L.P. PROGRAM	43.23%	**23.23%**	14.84%	**1.94%**	15.48%	1.29%
AFTER PROGRAM	15.15%	**29.29%**	25.25%	**5.05%**	19.19%	6.06%
WEEKEND	6.52%	**41.30%**	28.26%	**8.70%**	13.04%	2.17%

Table 3-2 Incident Type Distributions across Different Scenarios Indicating the Impact of H.E.L.P Trucks Activities

Overall, the analysis of June incident data for I-287 study area indicates an environment which is highly variable in terms of spatial and temporal distribution of the incidents for both west and east directions. Also, the negative influence of blockages is minimal with large majority of incidents positioned on shoulders. Furthermore, the average impact of “wet” road conditions on number of incidents is rather limited representing 12% for H.E.L.P. hours, 16% for after program hours, and 7% for weekend hours. Finally, when analyzing the effect of the services provided on potential hazardous situations, it should be noticed the significant difference of tow offs and debris percentages between H.E.L.P. and After Program / Weekend Operating hours. This difference is redistributed towards the percentage of H.E.L.P assisted disablements, indicating that the provided services helped minimizing the negative effects of unassisted vehicles such as debris and/or abandoned vehicles.

3.2.2.Detection Efficiency

In analyzing detection efficiency of H.E.L.P. service patrols, it is important to understand that they are an integral part of the local Intelligent Transportation Systems (ITS) architecture. In that context, the detection efficiency of patrol vehicles will also depend on the availability of other detection sources (such as Closed Circuit Television- CCTV, police or mobile phones), and on the operational characteristics of the fleet.

A filtering procedure was designed to analyze detection rate of H.E.L.P. trucks which was defined as percentage of incidents detected while roving out of total incidents serviced during program’s operating hours. The percentage of incidents detected while roving was identified by the difference between dispatch and arrival times recorded in the incident log database (zero if the truck detected the incident). For the study area, the resulted detection rate is one of the highest nation-wide with almost half of incidents detected by the continuous roving of H.E.L.P trucks. When compared with similar programs this percentage represents more than double than the usual detection rate (e.g. Chicago 28%; Seattle 18%; Atlanta 15%). Still, when analyzing detection efficiency of H.E.L.P program, this finding should be further explored taking into account similar data of other Beats in the coverage area.

3.2.3. H.E.L.P. Impact on Incident Response and Clearance Times

Capacity of a freeway service patrol to promptly respond and address the incidents is the one of the defining characteristics of FSP programs cost-effectiveness. Both time phases of incident development are dependent on the characteristics of the fleet and the prevailing traffic conditions, and the magnitude of their reduction is a parameter consistently used to estimate induced benefits of freeway service patrols in cost –evaluation procedures. While for the incident response phase the vital aspect is described by the time it takes for the response unit to reach the incident, for the clearance phase the particular on-site time plays the most important role.

As a general indication of H.E.L.P.'s effectiveness in reducing total incident time, a comparison of the response and clearance times among H.E.L.P., After-Program, and Weekend hours was implemented. Still, since prevailing traffic conditions for the three considered periods are different, the comparison will only define an upper bound on the incident time reduction generated by H.E.L.P trucks services and should be adjusted.

As expected, both response times (defined as the difference between dispatch and arrival time) and clearance times (defined as the difference between arrival and clearance time) exhibit an increasing trend outside H.E.L.P operating hours (Table 3-3 and Table 3-4). Response times with H.E.L.P in service are on average 12 minutes faster when compared with response times without H.E.L.P (e.g. weekends). Also, due to the experience of H.E.L.P staff/drivers in addressing such incidents, clearance times improve on average with 15 minutes when compared with weekend hours.

	H.E.L.P.	***AFTER PROGRAM***	***WEEKEND***
Mean [min]	**7.73**	**12.47**	**19.66**

Std. Deviation	13.53	13.62	19.06
Kurtosis	4.98	1.65	-0.15
Skewness	2.24	1.40	0.85
Minimum [min]	0.00	0.00	0.00
Maximum [min]	60.82	53.43	64.17
Count [incidents]	**129**	**86**	**39**

Table 3-3 Response Time Descriptive Statistics for H.E.L.P, After Program and Weekend Periods

	H.E.L.P.	***AFTER PROGRAM***	***WEEKEND***
Mean [min]	**35.52**	**42.48**	**50.27**
Std. Deviation	34.93	37.58	37.65
Kurtosis	1.13	3.05	1.13
Skewness	1.21	1.41	1.18
Minimum [min]	0.90	0.10	0.52
Maximum [min]	159.27	202.48	153.45
Count [incidents]	**129**	**86**	**39**

Table 3-4 Clearance Time Descriptive Statistics for H.E.L.P, After Program and Weekend Periods

The impact of H.E.L.P trucks in terms of response and clearance times can be observed in Figure 3-5 and Figure 3-6 which represents the relation between the different incident response/clearance times and their frequencies. The positive effect of the high detection rate reflects in the high percentage of incidents serviced by H.E.L.P within the 10 minutes interval after dispatch time (almost 80%), a percentage that is reduced to almost half for other scenarios (50% for After program hours and 40% for Weekend hours).

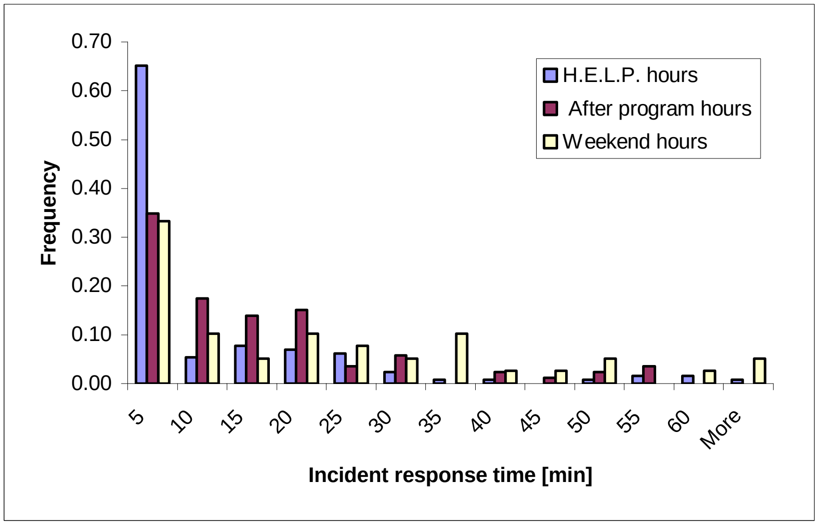


Figure 3-5 Response Time Distribution for H.E.L.P, After Program and Weekend Periods

Considering the same three scenarios, differences between clearance times are concentrated within 10 minutes of arrival time, indicating that with the increase of incident severity the effect of H.E.L.P. services is minimal (Figure 3-6). Nevertheless, the clearance time reduction for a 10 minutes time interval is significant (from a 20% during H.E.L.P hours to 5% during weekend hours).

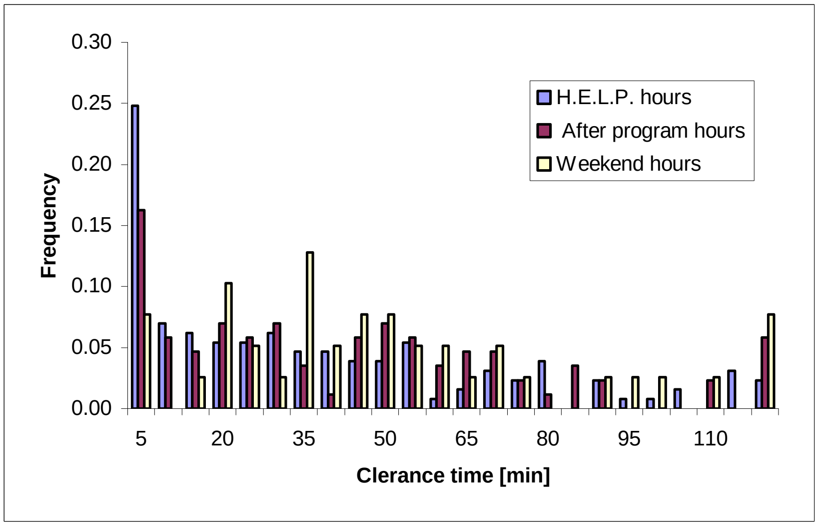


Figure 3-6 Clearance Time Distribution for H.E.L.P, After Program and Weekend periods

When using after program and weekend hours as alternatives representations of “without” H.E.L.P. conditions, the results of the response and clearance analysis indicate that H.E.L.P trucks contribute significantly to the reduction of total incident time. Detection efficiency of H.E.L.P trucks has a positive effect on the reduction of average response time, with a value of approximately seven minutes being one of the lowest nation-wide (Figure 3-7). Clearance times are also shorter, but only for those incidents whose severity does not require a service time longer then the program’s objective of 15 minutes.

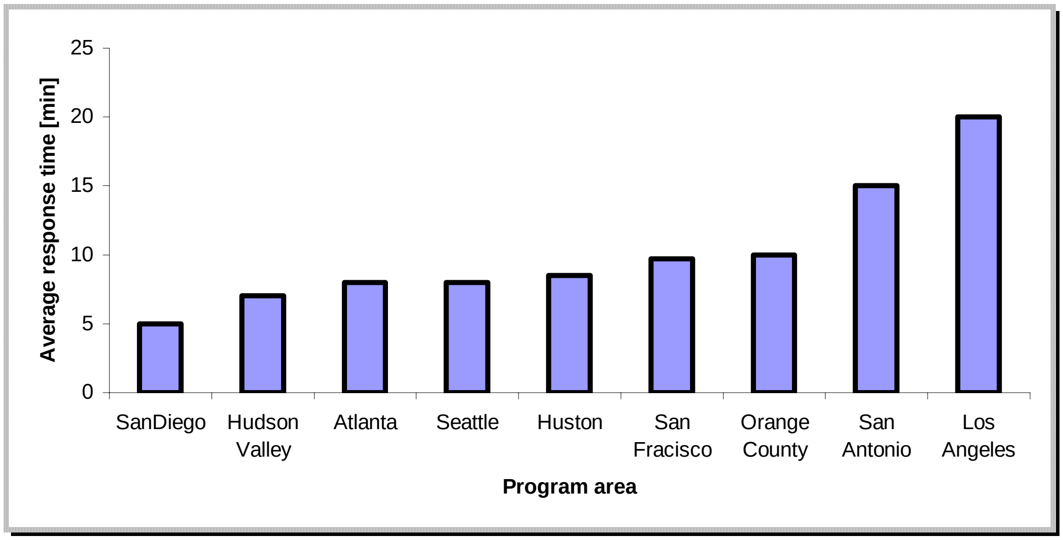


Figure 3-7 Nationwide Freeway Service Patrols Response Times

Response and clearance time reductions will be used in Chapter 3 to motivate the “without” H.E.L.P. operation conditions of the I-287 study area. Since the difference in total incident time between H.E.L.P. hours and Weekend hours is on average 30 minutes, and considering the difference between H.E.L.P hours and After program hours of 12 minutes, an adjusted value of 20 minutes was set as maximum threshold for the incident total time reduction.

3.2.4.Number of Secondary Incidents

The main assumption which identifies the secondary incidents formation is that a major accident will induce a shock-wave to the existing traffic conditions which will translate into speed reduction and queue formation. In addition, this degradation of traffic conditions caused by the combination between the severity of initial incident, the pre-incident congestion conditions, and the incident duration, may also lead to one or more secondary crashes. The main problem in identifying whether an incident is secondary or not results from the difficulty of finding the appropriate parameters which will accurately identify favorable conditions for secondary incidents formation.

The most frequent method used to define the number of secondary incidents is based on the fact that the incident information as it stands is sufficient in revealing the full extent of primary-secondary correlations. As a result, establishing a causal relation between a primary and a secondary incident will only require the proximity in time and space. However, this condition is only necessary but not sufficient, as it does not consider the actual representation of prevailing traffic conditions when the incident took place. Moreover, instead of uniquely defining the secondary incidents the proximity in time and space method is likely to produce bias results as it depends on the values of chosen thresholds.

To illustrate this argument, a filtering procedure of I-287 June incident data was programmed in VBA-EXCEL to estimate the number of secondary incidents when considering different scenarios of time and space proximity from a primary incident. The filtering procedure considered each incident to be primary and based on the time and space thresholds determined the results in terms of the numbers of secondary incidents. Figure 3-8 presents the results of the filtering procedure when the time difference between a primary and secondary incident is considered to be one, two or three hours respectively and the difference in location is considered to be one, two and three miles.

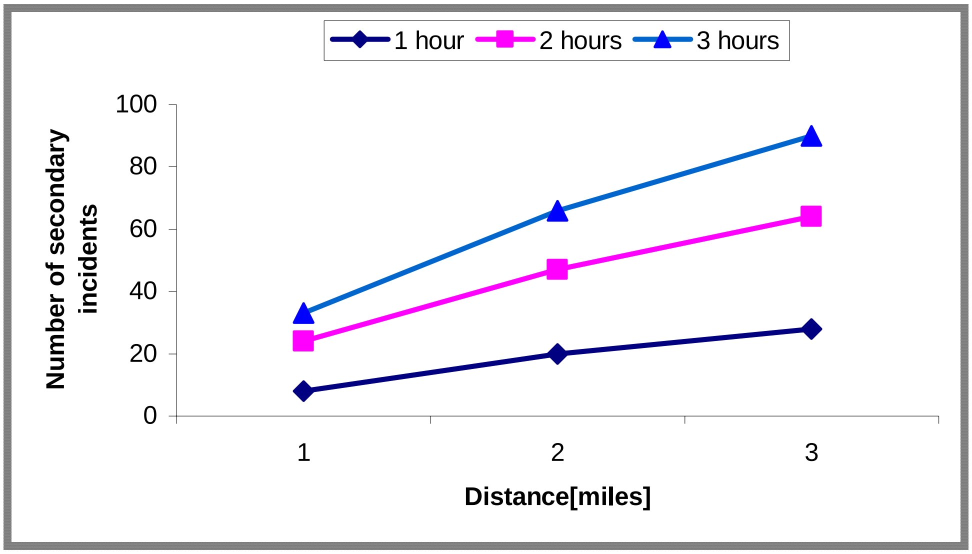


Figure 3-8 Number of Secondary Incidents Considering Different Time/Space Proximity Scenarios

Figure 3-8 provides a description of the number of secondary incidents which identifies the high dependence of the response with respect to the considered spatial and temporal boundaries. Since this case is a mere approximation of the real world conditions a procedure to estimate the number of secondary incident based on traffic conditions will be detailed in Chapter 6.

3.3. Highway Emergency Local Patrols (H.E.L.P.) Previous Studies

In terms of the program evaluation efforts, previous H.E.L.P. studies have focused solely on the statistical interpretation of the existing data. Using incident data from police records, the Garmen Study (1999) was the first research to evaluate the program effectiveness. The main objective of the study was the prediction of the occurrence rate of incidents based on traffic volume and length of roadway. One of the measurement exercises of this study was the evaluation of the incident duration with and without HELP service. The study findings indicate that H.E.L.P. program deployment results in a reduction of almost 30 minutes in the mean time per incident, a conclusion that is reinforced by the statistical interpretation of the I-287 incident data.

The second reference on program effectiveness is described by a 2001-2003 survey oriented database which indicates that the towing of disable vehicles and the clearing of travel lanes constitutes 25% and 15% of the total H.E.L.P. assists. Also, the continuous roving of HELP vehicles seems to play an important role in the incident detection process with 80% of the total incidents spotted by the patrols. While the first finding is supported by the I-287 database, detection efficiency results in smaller values (50%) with the average response time less then 10 minutes kept at the 80% level.

Finally, the customer satisfaction with respect to the H.E.L.P. services ranks high as the same database indicates that the 10 minutes goal is being maintained for almost 80% of the returned survey cards. This goal was balanced with the need to operate the program efficiently, without over-saturation of patrols along the highway system.

3.4. Conclusions

Based on statistical interpretation of I-287 study area incident logs, the services provided by the Highway Emergency Local Patrols have a significant impact in achieving a safer and more reliable highway environment. With the help of their specialized equipment, H.E.L.P. trucks prove to be extremely effective in addressing disabled motorists in need of small repairs, or in clearing the road area of eventual debris. Furthermore, their roving operations are instrumental in achieving a high detection rate (one of the lowest nation-wide) and reducing response times for motorists in need of assistance. Finally, in terms of clearance operations their effectiveness is limited to incidents which can be addressed within 15 minutes (small severity).

Chapter 4. **RESEARCH METHODOLOGY**

4.1. Introduction

With the main objective being the minimization of the response and detection time of incidents, roving patrols will be assigned to the freeway segments according to a deployment scheme. Upon detection of the incident, and if the circumstances permit it, the patrol vehicles will provide the necessary assistance to clear the area of the disturbance. Also, in the case of major incident patrol vehicles will act as an on-site incident management tool making the necessary arrangements for towing, ambulances, fire-trucks and other incident services. After the incident is cleared the patrol vehicles will resume the normal patrol operations. This entire process spans over the scheduled period of patrol when new vehicles take on the attributes of old ones.

One has to acknowledge that for the past two decades the state of research in the field of Incident Management (IM) has experienced a significant progress both from operational and planning perspective. Still when considering the multitude of factors involved in the above routine, it is obvious that the accurate representation of incident response operations becomes an extremely complex process in which the interaction between the operational characteristics of the fleet, incident distribution and traffic prevailing conditions has to be simultaneously considered.

For the most part with the notable exception of Pal (1999) the previous methodologies have been designed to evaluate case-specific programs using either statistical indicators (Dutta et al. 1997; Cuciti and Janson, 1995; Georgia DOT, 1996; Texas DOT, 1997; Hawkins 1993; Chang and Point-Du-Jour, 1999) or when available "before" and "after" data comparisons (Petty et al., 1996; Skabardonis et al., 1998).

While not comprehensive in nature, the current research is unique in that it represents the development of an integrated methodology to characterize the effectiveness of freeway service patrols response with **respect to the variability of traffic prevailing conditions at the microscopic level**. Demand for service or the incident distribution is considered to be deterministic with Hudson Valley data used as an evaluation benchmark. Also, while the impact of total incident time reduction on program effectiveness is addressed by means of stepwise increments, the exact implications of that change on the operational characteristics of the H.E.L.P. fleet are not detailed.

In using a simulation model as the main analysis tool, the current research reveals a dual motivation which relies on one hand on the limitations of the existing data with respect to the model calibration needs and on the other hand on the exploration of incident development in different traffic conditions. While this is computational intensive when compared to an analytical approach, it has the advantage of better representing the symplectic character of the traffic flow in terms of inherent complexities induced by the incident development.

4.2. Design of Experiments

The current methodology will be organized as a **Multi-Layer Sensitivity Analysis (MLSA)** on the Benefit-Cost ratio considering the variability of *incident capacity*, *traffic volume* and *driver aggressiveness*. The benefits will be identified by the reduction in the approach delay, fuel consumption, emissions and secondary incidents considering "WITH" and "WITHOUT" H.E.L.P. operations, while the costs will be described by the contractor's hourly rate per patrol vehicle. Since micro-simulation is used as main evaluation tool the methodological framework will be constructed around CORSIM characteristics by means of a core three step procedure applied to both "with" and "without" scenarios (Figure 4-1).

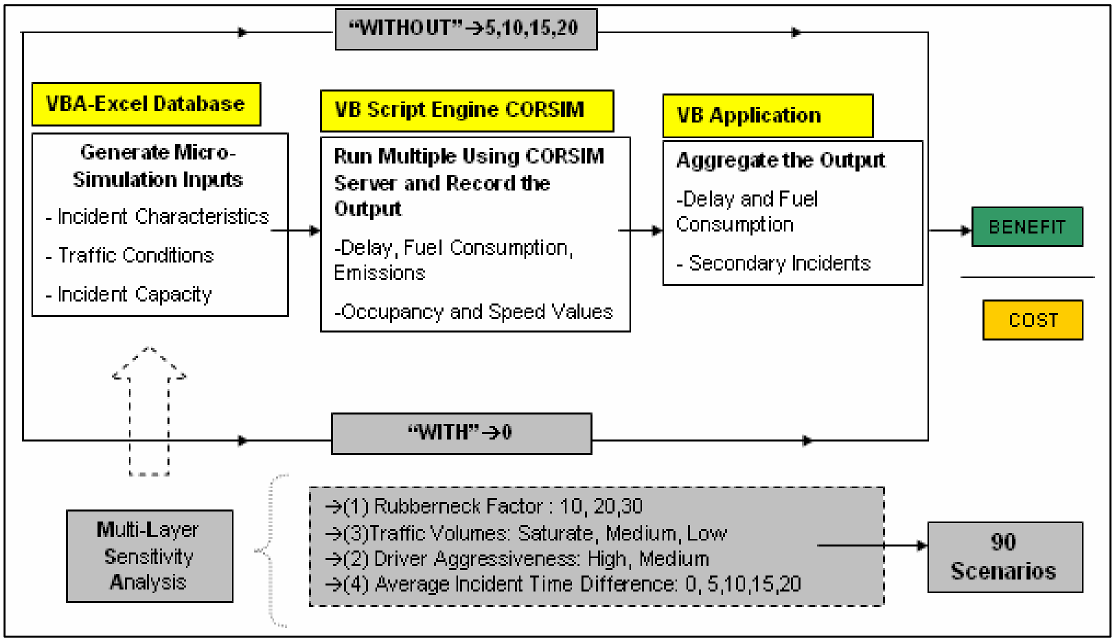


Figure 4-1 Methodology used for H.E.L.P Cost-Effectiveness Evaluation

For the ease of later reference several notations will be defined. The characteristics of the current set of “n” incidents are denoted by **I (l_i, o_i, t_i, b_i); (i=1…n)** where “l_i” represents the incident location, “o_i” the incident onset time, “t_i” the incident total time, and “b_i” the extent of incident cross sectional blockage. The incident environment is represented by a multivariate function with the traffic volumes (“v”), driver aggressiveness (“d”) and rubberneck factor (“r”) as the main parameters; ***f*****(v, d, r)**. Finally “with” and “without” H.E.L.P. operations will be represented by a function of the average reduction (“rt”) in the total time of incidents;

$\Re(rt)$. A representation of the entire simulation process using pseudo-code is presented in Figure 4-2.

```
n- number of incidents;  m- number of volume scenarios
p –number of driver aggressiveness scenarios
s - number of rubberneck scenarios
rt =0 minutes
Do While rt < Maximum Incident Time Saving (assumed =20 minutes)
Given Incident Distribution $I(l_i, o_i, t_i, b_i)$; i =1 to n
    For v=1 to m
        For d= 1 to p
            For r = 1 to s
                Replicate the Incident Conditions $S_{\Re}(I(l_i, o_i, t_i, b_i); f(v, d, r))$
                Run Micro-simulation for Model State $S_{\Re}$
            End for
        End for
    End for
Aggregate the Output Measures of Effectiveness (MOE)
Compute the difference between the Model States MOE's
rt=rt+5
End Do
```

Figure 4-2 Pseudo-Code for H.E.L.P. Cost-Effectiveness Evaluation

Given the incident distribution, the environment function and the reference provided by the total incident time the input state or scenario "S" to be analyzed will be defined by $\mathbf{S_{\Re}(I(l_i, o_i, t_i, b_i); f(v, d, r))}$.Using the previous notations the freeway service patrol programs improvement will be induced by the average reduction in the total incident time which can be represented as the difference between two states $\mathbf{S_{\Re initial}}$ and $\mathbf{S_{\Re final}}$.

For the current analysis the considered values of the time reduction (rt), volumes factor (v), driver aggressiveness (d) and rubberneck factor (r) are described in Table 4-1 with their justification being explored in Chapter 5.

Time reduction	Volume Factor	Driver aggressiveness	Rubberneck factor
0, 5, 10, 15, 20	1, 1.5 , 2	0.85 , 1.05	10, 20, 30

Table 4-1 Multi-Layer Sensitivity Analysis Parameters

The following sections will further detail the presented conceptual framework, exploring the main assumptions of the model and their rationale. Section 4.2.1 presents an overview of the CORSIM incident model used to replicate H.E.L.P. impact on traffic conditions. Section 4.2.2 motivates the need of multiple runs and evaluates the model computational efficiency with respect to its variance. Section 4.2.3 describe the input, run and output simulation procedures and state their degree of applicability. Section 4.2.4 concludes the chapter by pointing out the advantages and deficits of the current research methodology.

4.2.1. CORSIM Model for Replicating Incident Conditions

The operational design of the freeway service patrols will impact on the way incidents will be addressed in terms of the response and clearance time. However, since the focus of the current research is the analysis of H.E.L.P cost-effectiveness with respect to the variations of the traffic conditions, the operational aspects are considered fixed and will not be further explored. The analysis will compute H.E.L.P. program benefits as a reduction in Total User Cost (aggregated as the approach delay, fuel consumption, emissions, and secondary crashes) for different traffic conditions considering a reduction in total incident time of 5, 10, 15 and 20 minutes (values motivated by findings of Chapter 2).

While CORSIM does not have the provision to explicitly address freeway service patrol operations, in terms of replicating incidents conditions it represents one of the leading simulation packages (Payne et al, 1997; Skabardonis, 1999; Wang et al. 1999; Crowther 2001). The CORSIM incident generation procedure is comprehensive in that it simulates the spatial (incident location and length) and temporal characteristics (incident onset time and duration) and their effects on the existent capacity (rubberneck factor or complete blockage). Still, one of the main drawbacks is that the internal mechanism does not allow for the onsite incident time to be greater then 9999 seconds which practically restricts the current analysis to isolated incidents.

In order to replicate the impact of H.E.L.P trucks on I-287 traffic conditions, the designed CORSIM model was adjusted to account for incident characteristics **(l_i, o_i, t_i, b_i)**, prevailing traffic conditions (**v, d, r**), road condition, anticipatory reaction of drivers, and incident length. While the large majority of simulation parameters had well defined values resulted from incident or traffic data, the last two (incident length and anticipatory reaction of drivers) required assumptions on their values. The author's choice was to define both values such that they have a minimum impact on disrupting highway operations. That implies that the microsimulation results (or the measures of effectiveness of H.E.L.P operations) **should be interpreted as lower bounds (conservative values) of H.E.L.P impact on highway operations**.

Anticipatory reaction of drivers to H.E.L.P on-site operation was implemented using a shoulder blockage with the hypothetical warning sign positioned at a distance of $\mathbf{L}_{ws}$ =150 ft. The incident length $\mathbf{L}_i$ was adjusted to take into account the number of vehicles involved staring with a minimum distance of 60 feet (the length of two vehicles, disabled and assistance truck $=L_i$). Figure 4-3 represents CORSIM model layout for a shoulder incident with a single vehicle involved. The position of the warning sign indicates the start of rubbernecking phenomenon which perpetuates in the impact area (shaded) with different intensities depending on the cross and longitudinal location with respect to the incident.

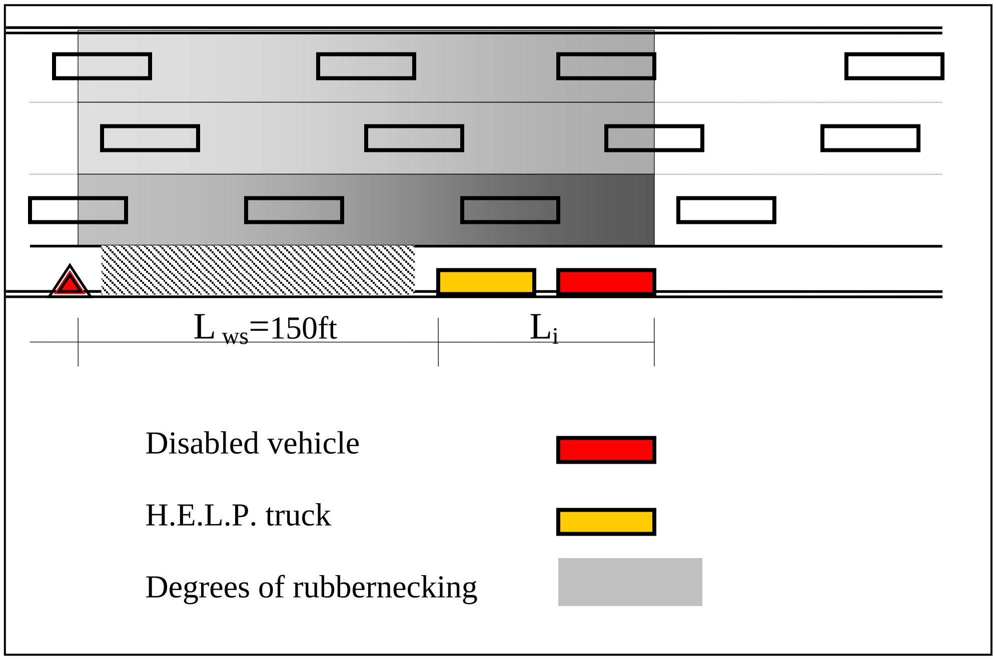


Figure 4-3 Layout of H.E.L.P. CORSIM Model for a shoulder disablement

4.2.2. Computational Efficiency

Since micro-simulation is the main analysis tool, the relation between the computational effort and the variability of the results had to be explored. The exact correlation between the variability of the estimated values and the number of runs needed to achieve is mainly a function of the design characteristics of the model. Still, a minimum value of 3 runs is recommended in order to provide some idea on the model output variability. If the computational effort is prohibitive even for this boundary case the simulation output should not be used to draw any conclusion on the overall performance of the model.

The importance of the proper usage of traffic simulation models has been previously emphasized by Rahti and Nemeth (1985) and Rahti and Venigalla (1992). The authors warn about the danger of misusing the simulation by adopting a “black-box” perspective without considering the specifics of the model output, the validity of conclusions and the robustness of the experiments. While the first two aspects pertain to model calibration by means of verification and validation, model robustness indicates the validity of model response with respect to changes in the explanatory variables and implied causal mechanism.

In order to analyze the effects of multiple runs on the quality of the delay output a pair wise comparison between the actual and the mean performance of the system was implemented for the scenario $\boldsymbol{S_{\Re(20)}(I_{i=155}; f(2,\ 0.85,\ 30\%))}$. Therefore, the analyzed system is represented by the CORSIM H.E.L.P. model for the case of a volume factor of 2, mean car following sensitivity factor of 0.85 seconds, and a rubberneck percentage equal with 30. Assuming that the resulted incident total delays are independent and identically distributed (IID) random variables, Paired-t 95% confidence intervals were constructed with respect to the “mean delay” considering the case of three, five and ten runs (Equation 4-1, 4-2 and Figure 4-4).

$$Var[\overline{D(n)}] = \frac{\sum_{j=1}^{n} [Dj - \overline{D(n)}]^2}{n(n-1)} \tag{4-1}$$

$$\overline{D(n)} \pm t_{n-1,1-\alpha/2} \cdot \sqrt{Var[\overline{D(n)}]} \tag{4-2}$$

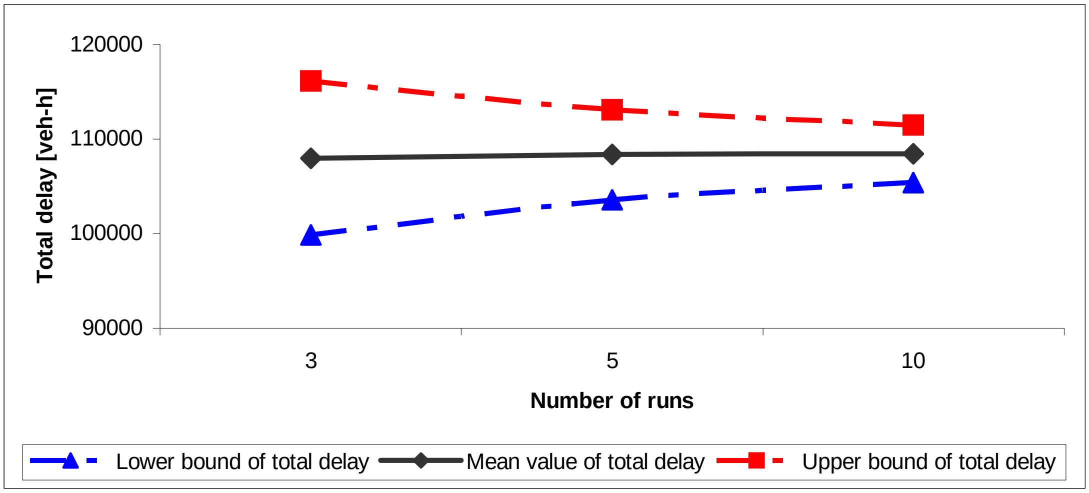


Figure 4-4 Convergence of H.E.L.P. CORSIM Model in Terms of Total Delay for Scenario $S_{\Re}(20)(Ii=155;f(2, 0.85, 30\%))$

The results indicate a small variability across the number of runs of total delay correlated with a relatively quick convergence of half width of 95% confidence intervals (difference from mean is for 7.53% for three runs, 4.40% for five runs, and 2.80% for ten runs). In terms of computational efficiency, for a single run, the model translated the necessary 313 hours of simulation time necessary to replicate all the H.E.L.P incidents (155) to one hour and 45 minutes of effective running time. The hardware platform used for this test was a Pentium 4 CPU with 3.40 GHz and 1.99 GB of RAM. Using the results of this test and considering the convergence of half widths percentages, the number of runs for the CORSIM H.E.L.P model was selected to be five.

4.3. Input Parameters of H.E.L.P. Model

The input files generation module was constructed using the VBA-EXCEL programming environment. The entire process was expedited by the customized design of a database comprising all the relevant information related to the incident and prevailing traffic characteristics and the fact that CORSIM has a straightforward tabular input format. A description of the main records used to replicate the incident conditions is presented in Table 4-2.

Record Identifier	**Description**
RT 2	• *Run Control* : o Start simulation time (*entry 16*) o Headway distribution type (*entry 8*) o Simulation random seeds (*entries 5,18,19*) o Freesim off-line point processing (*entry 2*) o Initialization period (*entry 4*)
RT 3	• *Number of Simulation Periods and Their Duration*
RT 20	• *Operational Characteristics* o Pavement condition (*entry 6*) o Free-flow speed (*entry 8*)
RT 28	• *Detector Characteristics*
RT 29	• *Freeway Incident Simulation Procedure* o Incident codes for the 3 lanes+shoulder (*Entries 3*-*6*) o Longitudinal location (*entry 14*) o Length of the incident (*entry 15*) o Start(onset) time of incident (*entry 16*) o Duration of the incident (*entry 17*) o Rubberneck factor (*entry 18*) o Location of warning sign for blockage (*entry 19*)
RT 50	• *Entry Volumes*
RT 64, 67	• *Pooling Frequency for Detectors* • *Detectors Identifiers*
RT 68	• *Driver Aggressiveness in Terms of Car Following Mechanism*

Table 4-2 Records Entries Used to Construct H.E.L.P. CORSIM Model

4.4. CORSIM Running Server

For the total of the 90 scenarios implemented in the MLSA the total running time of the simulation model was approximately 700 hours. In order to automate the multiple running processes and to provide a quick output, the second part of the analysis core procedure took advantage of the scripting capacities already existent in CORSIM 5.1.

The main advantage in using CORSIM scripting platform is that the existent classical Microsoft Visual Basic Script (VBS) engine is enriched by the existence of three customized interfaces design to facilitate the operability of the simulation server. The user manual identifies the Output View Control Interface designed to enable script writing, Script Support Interface designed to provide functions of control and execution for the scripts and CORSIM Server Interface designed to control the settings and execution of the micro-simulation.

A modified version of a “Multi Run Many Cases Saving Network Data” default script was implemented. The differences between the default and current format of the script had to account for the increase in the output complexity. Therefore adjustments were made to accommodate for multiple measures of effectiveness (delay, fuel consumption, emissions) and detector data (occupancy for the 76 sectional sections of hypothetical Doppler detectors).

4.5. Output Parameters of CORSIM H.E.L.P. Model

One of the most demanding tasks of the simulation procedure as far as CORSIM capabilities were concerned was the aggregation of simulation results. While the script engine has the advantage of facilitating the repetitive run of the micro-simulation server, it also greatly limits the output flexibility. Since CORSIM results were incorporated in text files (.OUT format) a substantial amount of time was dedicated to programming customized data extracting procedures. Because of the ease in manipulating multiple files Visual Basic 6.0 was chosen as the main programming platform.

The Output Procedure was designed to address the aggregation of main measures of effectiveness (Delay, Fuel Consumption and Emissions) but also to gather mean occupancy rates values from detectors which will indicate the existence of a feasible area for the secondary incidents occurrence. While the first part of the output generation procedure is straightforward (the aggregated result of the measures of effectiveness is the summation of the isolated incidents outputs), the secondary incidents output procedure is more complex and it will be detailed in the following chapter.

Due to the fact that micro-simulation is extremely expensive in terms of computational time, the bounds on parameters which define prevailing traffic conditions had to be preprocessed such that the cases considered will be relevant to the highway environment in which freeway service patrols operate. Preprocessing of the bounds of the main sensitivity analysis parameters (traffic volumes, rubberneck factor, and car-following logic) was achieved by exploring the empirical evidence of the operational characteristics of the freeway service patrols. The following chapter will present an overview of these findings.

Chapter 5. **H.E.L.P. MULTI LAYER SENSITIVITY ANALYSIS (M.L.S.A.) PARAMETERS**

5.1.1.Traffic Volumes

Highway Capacity Manual provides a general method to categorize the service quality of a road segment. The Level of Service (LOS) national indicators designated with letters from A (best) to F (worst) are qualitative representations of roadway operating conditions based on multiple factors such as speed, travel time, maneuverability, delay and safety. For example, considering a free flow speed of 65 mph (above 10 miles then the posted value on I-287) the HCM level of service criteria are presented in Table 5-1.

65 mph Free-Flow Speed			
Density (pc/mi/ln)	**Speed (mph)**	**Maximum (V/C)**	**Max Service Flow MSF (pcphpl)**
<10.0	>65	0.295/0.283	650
<16.0	>65	0.473/0.457	1,040
<24.0	>64.5	0.704/0.673	1,548
<32.0	>61	0.887/0.849	1,952
<43.4	>53	1	2,200/2,300
Variable	Variable	Variable	Variable

Table 5-1 Highway Capacity Manual LOS for 65 mph Free-Flow Speed

Although Highway Capacity Manual LOS values are general indicators of roadway operating conditions, in the M.L.S.A. they were used to determine the maximum service flow rate (MSF) for different traffic volumes scenarios. According to values of MSF from Table 5-1, the microsimulation input traffic volumes were adjusted to represent three possible scenarios (volume factors=1, 1.5 and 2). The adjustment process guarantees that for a volume factor of one the traffic volumes will not be higher then 1040 pcpphpl (LOS B), for a volume factor of one and a half the traffic volumes will not be higher then 1548 pcpphpl (LOS C), and for a volume factor of two traffic volumes will not be higher then 1952 pcpphpl (LOS D). The main reason for not considering saturated and oversaturated conditions (LOS E and F) was the existence of recurrent congestion as main influencing factor. The fact is that this phenomenon is highly predictable and less addressable as far as the operations of freeway service patrol are concerned. Moreover, in this case other incident management strategies such as route diversion or ramp metering take over as primary methods to address negative impacts of congestion.

With respect to the data characteristics the hourly values of traffic volumes for the month of June 2004 were representative for the nation's urban freeways both from weekend and weekday perspective (Figure 5-1).

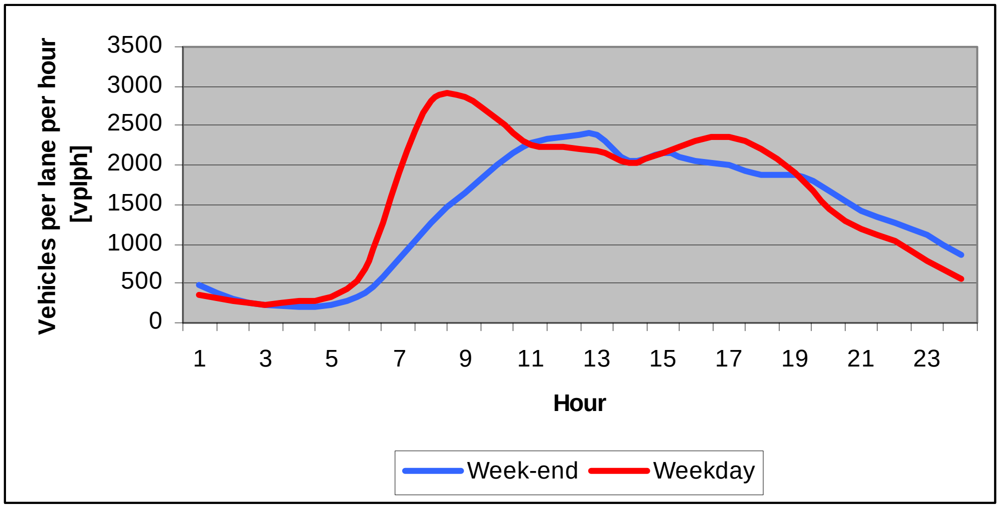


Figure 5-1 Hourly Weekday and Week-end Traffic Volumes Profiles

While the LOS concept was used to define different boundaries on the simulation traffic volumes (scenarios), this approach will not be complete without estiamting the road capacity value. As the maximum flow rate at which the traffic can pass along a roadway within a “particular set of conditions”, the capacity has by definition a highly unpredictable nature. The difficulty in quantifying such a measure relies on finding the “exact” conditions or the mix of parameters that will be the closest to real-world environment. A detailed microsimulation calibration procedure will generally consists of two main steps with a general network wide estimation of the capacity significant parameters and a detailed link based evaluation for the fine tuning. This optimization procedure will have as final objective the minimization of the sum of the errors between the simulation and real world operations with the mean following headway, the driver reaction time, the critical gap for lane changing maneuvers and, the minimum separation for stop and go conditions being the main parameters.

For the designed incident simulation model the existing traffic data made possible a pre-calibration of the characteristics of the traffic mix in terms of lane percentage distribution (30%, 50% and 20%), hourly volumes and truck percentages. However, the actual value of the capacity was not detailed by means of comprehensive calibration procedures but resulted as the maximum H.E.L.P model throughput when considering the effect of internal vehicle generation mechanism, and car following logic. For the internal vehicle generation mechanism the default value of 1.6 seconds was used, while for the car following logic values of 0.8 and 1 second (describing the distribution of car following sensitivity factor - Section 5.1.2) were implemented. Using the average throughput value for 30 runs as capacity descriptor, and a nominal segment similar to I-287 configuration (number of lanes =3, length= 10 miles) the capacity results indicate values of approximately 2097 vphpl for the medium car following sensitivity factor (1 second), and 2233 vphpl for the high car following sensitivity factor (0.8 seconds) both close to HCM saturation values.

To conclude, both traffic volumes and capacity of CORSIM H.E.L.P. model were adjusted to replicate three HCM levels of service (B, C, and D) for a highway segment which has a 65 free-flow speed (I-287 segment). Still, this defining structure is only part of the information that will describe the M.L.S.A. scenario, and it will be further detailed, considering the impact of the capacity reduction generated by incidents. Since the incident capacity reduction scenario will be described by the CORSIM car following logic and rubberneck factor, a critique of these two parameters is presented in the following sections. Also, based on the characteristics of the H.E.L.P study area, relevant values are proposed.

5.1.2. Car Following Behavior

The use of **car following sensitivity parameters** to describe the quality of the service provided is not new, Payne et al. (1997) reporting a theoretical increase in the capacity from the default value of 2350 vphpl to about 3300 vphpl. However, the exact relation between this descriptor and the resulted capacity is far from being crisp and several authors recommend caution in using it as even small changes in the input can result in large deviations in the output values (May et al., 2001; Bloomberg and Dale, 1999; Hall et al., 2000).

CORSIM uses Pitt car-following model to describe the interaction between successive vehicles. According to Crowther (2001) the headway of a vehicle is determined by the jam density conditions and the kinematic characteristics of the follower vehicle with respect to the leader (Equation 5-1). At the steady state when

$\Delta u \rightarrow 0$ the Pitt model is similar to Pipes model revealing a liner relation between the speed of the vehicle and the resulting distance headway.

$$h = h_{jam} + C_{fs} \cdot u + b \cdot C_{fs} \cdot \Delta u^2 \qquad [5\text{-}1]$$

Where:

h_{jam} – distance headway when vehicles are completely stopped

C_{fs} – car following sensitivity factor with values between 0 and 2

b – calibration constant which equals 0.1 when the speed of the follower vehicles is greater then the speed of the lead vehicle and 0 otherwise

Due to the linearity of Pipes model and considering the fundamental relation of a traffic stream, the freeway capacity can be determined by replacing in [5-2] the speed of the vehicle with the free-flow value (Equation 5-1)

$$q_c = \frac{u_f}{h_j + C_{sf} \cdot u_f} \qquad [5\text{-}2]$$

While free-flow speed and jam density can be determined by field measurements the empirical evidence of car-following factor is harder to determine. The main assumption in CORSIM is that the car-following factor is described by a uniform distribution resulting from dividing the driver population into 10 types and assigning different sensitivity factors (C_{sf}) to each category, where typical C_{sf} can take on values from 0.1 to 2.

Equation 5-2 indicates that for a steady state scenario capacity calibration can be achieved by means of free-flow speed, car-following sensitivity factor and jam density. However, it is important to point out that this analytical result is restricted to the assumptions made on the lane-changing mechanism, the characteristics of the traffic mix and the internal vehicle generation procedures of the micro-simulation model.

In terms of replicating **the lane changing mechanism** CORSIM uses a combination of discretionary, mandatory and lane positioning algorithms. The mandatory and lane positioning algorithms are more easy to implement since they represent defined constraints in driver’s decisions (e.g. the obstructed or turn lane for the first case and the origin-destination path for the second case). Discretionary algorithms on the other hand, are more subjective because they have to describe passing a “slower” vehicle or positioning on other lanes because of perceived safety reasons. No matter which algorithm is employed at a certain moment, in order to execute the lane changing maneuver the drivers will have to find an acceptable gap and make sure that the speed differential does not pose any hazard. Due to the complexity of the three algorithms the implementation of the lane-changing behavior is one of the most challenging tasks in programming a micro-simulation package and also one of the main sources of irregularities.

In CORSIM the main parameters used to define lane changing mechanism are the gap acceptance, the multiplier for desire to make a discretionary change and the advantage for discretionary lane change. The gap acceptance is defined for 10 types of vehicles having default values between 1.5 and 7.5 seconds. The multiplier for desire to make a discretionary change is the representation of the driver aggressiveness and has values between 0.1 (extremely safe) and 1 (extremely aggressive). Finally, the advantage for discretionary lane change represents the response of the traffic environment to lane-changes or yielding the way within flow irregularities and can take values 0.1(extremely non-permissive) and 0.9(extremely permissive).

When relating to both mechanisms previous micro-simulation experiments have indicated that the maximum achievable capacity in CORSIM is approximately 3000 vphpl, a value obtained considering the vehicular flow at the saturation level. For this case (Table 5-2) the critical set of parameters of H.E.L.P simulation were set to minimize the impact of the lane-changing disturbances while defining the car-following sensitivity to be extremely aggressive and the speed of vehicles close to the free-flow value.

Parameter	**Value**
• Multiplier for desire to make a discretionary lane change • Advantage for discretionary lane change • Time to complete a lane change maneuver • Gap acceptance parameter	0.1 [0 to 1] 0.9 [0 to 1] 2 sec 3
• Free flow speed	65 mph
• Car following sensitivity factor • Pitt car following constant • Average vehicle length • Minimum separation for generation of vehicles • Leader's maximum deceleration perceived by the follower	0.1 [0 to 2] 3 feets 19.5 feets 1 sec 15 ft/sec
• Headway Distribution	Uniform

Table 5-2 CORSIM Maximum Capacity Critical Parameters

Moreover, in the current simulation model the representative values for the car-following and lane-changing behavior were assimilated with a mean response of the system. The distribution of the car-following factors was assumed to be representative for a medium towards high driver aggressiveness with the Pitt factor having a value of 10 ft and the average vehicle length of approximately 14 ft (Table 5-3). Also the discretionary lane-changing mechanism was kept at the default value with a 50% change to make a lane change and 40% that the surrounding environment will adjust to accommodate it.

C_{sf}	1	2	3	4	**5**	6	7	8	9	10
high	1.25	1.15	1.05	0.95	**0.85**	0.75	0.65	0.55	0.45	0.35
medium	1.45	1.35	1.25	1.15	**1.05**	0.95	0.85	0.75	0.65	0.55

Table 5-3 Car Following Sensitivity Factors for Multi-Layer Sensitivity Analysis

5.1.3.Rubberneck Factor

The phenomenon of “rubbernecking” is triggered by driver’s curiosity to disruptions which are in the proximity while not posing any relevant constraints to their present path (e.g. shoulder blockages, incidents on the other side of the road). As an indirect measure of impedance, the size and propagation of rubbernecking is very hard to quantify. Unlike a classical blockage scenario in which the incident capacity can be explained using relatively straightforward relations, rubbernecking will rather have an associated likelihood value. In other words, the classical reaction of drivers slowing down to observe the incident might or might not take place depending on the existent environment and individual behavioral characteristics.

CORSIM has the ability to replicate rubbernecking by proportionally increasing the distances at which the vehicles are following one another. The current state of a lane in the incident area will be either described by normal capacity, reduction in capacity by means of a rubberneck factor or complete blockage. For the current study the rubberneck factor was used as the equivalent of capacity reduction for simulation instances which represent shoulder blockages and as a complement for the total lanes closures. For example considering a 3-lane road segment with a 20% percent rubberneck factor distributed uniformly for two lanes and a one lane blockage will result in a 46.67% overall capacity reduction (Equation 5-3)

$$CR_{3lanes} = 100 \cdot \frac{1}{3} + 20 \cdot \frac{1}{3} + 20 \cdot \frac{1}{3} = 46.67\% \qquad [5\text{-}3]$$

In terms of the rubberneck factor values, the capacity reduction developed by Lindley (1987) and later reinforced by Sullivan (1998) were used as general thresholds for CORSIM H.E.L.P. model (Figure 5-2).

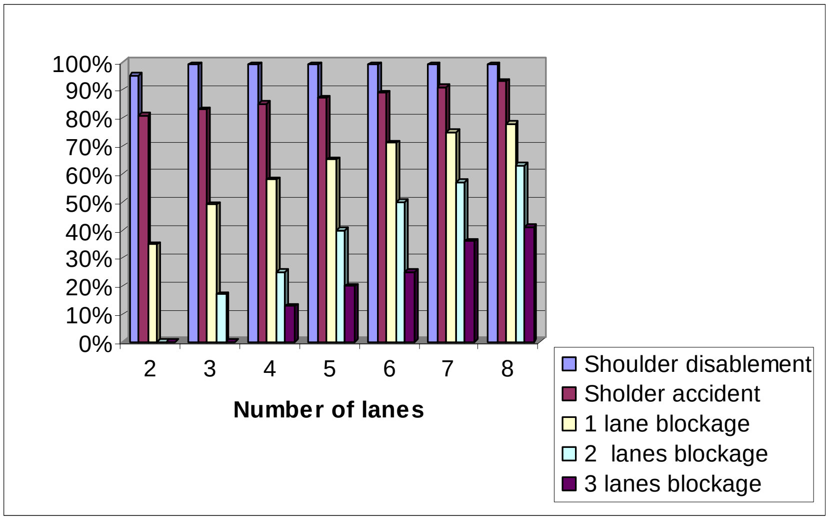


Figure 5-2 Fraction of Freeway Capacity under Incident Conditions (Lindley 1987)

Still, since the exact CORSIM incident capacity reduction is not a straightforward measure, and depends on the combination of car logic and rubberneck factor, the same experiment used for determining H.E.L.P. CORSIM model capacity was replicated for a shoulder incident considering rubberneck factor values of 10%, 20%, and 30%. The results presented are presented in Table 5-4 and indicate variations from the expected value of the capacity reduction which have to be considered when reporting the results of each scenario.

Rubberneck factor	**Medium** Driver Agressiveness		**High** Driver Agressiveness	
	Capacity [vphpl]	Percent Reduction	Capacity [vphpl]	Percent Reduction
	2097	0%	2223	0%
10%	1917	**10%**	2108	**5%**
20%	1525	**20%**	1993	**15%**
30%	1363	**35%**	1683	**25%**

Table 5-4 Incident Capacity Reduction for Multi-Layer Sensitivity Analysis

Considering Section 5.1.2.and Section 5.1.3 findings, the defining structure of the M.L.S.A. scenarios is described by Table 5-5. The correspondence between H.E.L.P. microsimulation parameters (volumes- column [1], car following sensitivity factor distribution – column [3], and rubberneck factor- column [4]) and descriptors of highway operations is presented in columns [2] and [5].

[1]	**[2]**	**[3]**	**[4]**	**[5]**
Traffic Volumes [pcphpl]	**Level of service**	**Mean of CFSF [sec.]**	**Rubberneck factor [%]**	**Incident capacity reduction [%]**
<1000	**B**	0.8	10	**5**
<1000	**B**	1	10	**10**
<1000	**B**	0.8	20	**15**
<1000	**B**	1	20	**25**
<1000	**B**	0.8	30	**30**
<1000	**B**	1	30	**35**
<1500	**C**	0.8	10	**5**
<1500	**C**	1	10	**10**
<1500	**C**	0.8	20	**15**
<1500	**C**	1	20	**25**
<1500	**C**	0.8	30	**30**
<1500	**C**	1	30	**35**
<2000	**D**	0.8	10	**5**
<2000	**D**	1	10	**10**
<2000	**D**	0.8	20	**15**
<2000	**D**	1	20	**25**
<2000	**D**	0.8	30	**30**
<2000	**D**	1	30	**35**

Table 5-5 Correspondence CORSIM H.E.L.P Parameters - LOS and Incident Capacity Reduction

Chapter 6. FEASIBLE AREA FOR SECONDARY INCIDENTS

6.1.1. Secondary Incidents Dissemination

One of the main contributions of the current study is defined by the exploration of the relation between the dynamic queue formation and the number of secondary incidents. As a first observation it is important to point out that the way in which secondary incidents are defined will impact the accuracy of results and that the validity of the theoretical frame proposed will ultimately rest on their empirical evidence.

Several studies tried to establish reasonable thresholds in defining the secondary incidents. Proximity in time and space with respect to the primary incident is obviously one of the most common approaches either by means of fixed (Giulliano et al. 2004) or variable values (Chang and Point-Du-Jour 2001). Although this filtering procedure holds an intuitive value, as already proven, it does little to explain the exact relation between the queue formation and the secondary incident occurrence.

In the same study, Giulliano et al. (2004) acknowledge this problem and further investigate the exact nature of this relation by designing a filtering procedure which correlates the incident location data with detector evidence of queue formation. The upstream shock wave formation in both directions is used to provide feasible boundaries for the occurrence of secondary incidents. However the filtering procedure was applied after considering the proximity in time and space and due to the loop detector data limitations only 16% of the 180 pair-wise incidents were subject of analysis. Moreover, secondary incidents location with respect to the queue formation were defined using an analytical procedure defined by Al Deek et al. (1995) which does not take into account nonlinearities of shock-waves.

While the main idea of shock wave investigation using detector data remains the same as the one introduced by Giulliano et al., the novelty of the current research rest in the attempt of explaining the dynamic queue formation using a recognition algorithm of the mean occupancy rates patterns. For the purpose of current analysis secondary incidents were defined as the set of incidents occurring in the high occupancy (congested) area resulted in the proximity of the primary incident. However, instead of subjective threshold values "proximity" limits were determined by values of mean occupancy rates provided by model detectors which are greater then a user-defined threshold **(κ)**. While one would argue that the "time-space" proximity bias was changed to a mean-occupancy rate bias, using κ value has two major advantages. The first one is that the relation between primary and secondary incidents is now undoubtedly revealed by the evidence of traffic conditions degradation. The second one is that the relation between different values of κ and the number of secondary incidents can be easily studied, and ultimately used to determine the location of secondary incidents with respect to the queue formation.

Corresponding to the HCM Level of Service thresholds three intervals were defined to describe uncongested flow conditions (percent occupancy 0-10%), borders of unstable operations (percent occupancy 10- 20%) and congested flow conditions (percent occupancy > 30%). Using the segmentation provided by the detector position and pooling characteristics, a typical occupancy map of an isolated incident is the representation of the dynamic queue formation with respect to the primary incident, providing a feasible area for the occurrence of secondary incidents (Figure 6-1).

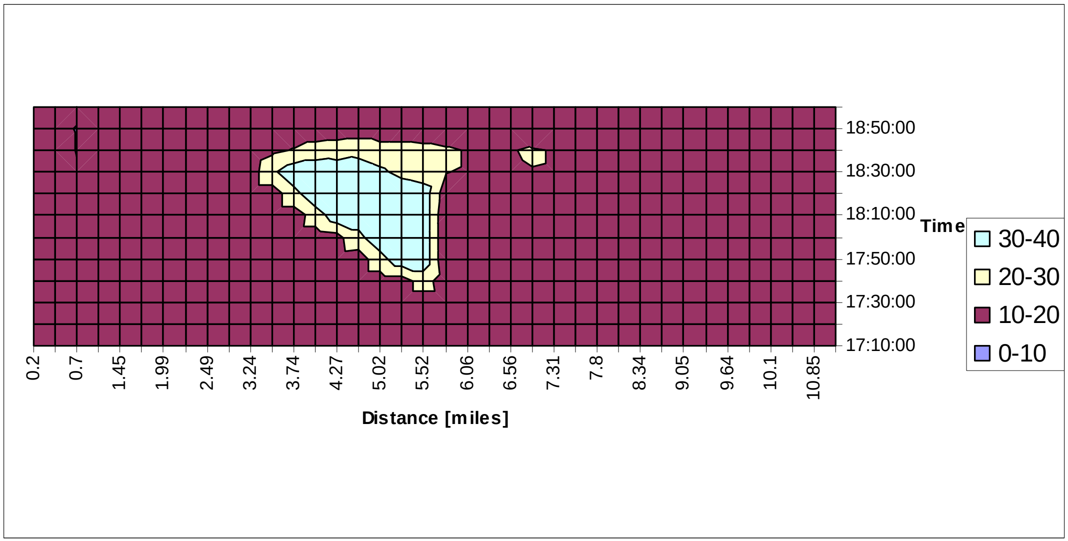


Figure 6-1 Occupancy Map for an Isolated Incident

In the most general form the density map for an isolated incident has a polygonal shape with boundaries defined by a backward-forming shock wave, a forward-recovery shock wave and frontal and rear stationeries shock waves. Also depending on the characteristics of the traffic within the high density area, the boundary between the congested conditions and recovery conditions (after the incident has been cleared) can be described either by a forward or backward recovery shock wave. The first one occurs when congestion is influenced by the demand decrease in time below the bottleneck capacity while the second one is the result of the increase in the discharge rate of the bottleneck capacity above the demand values.

Although easier to implement from the analytical point of view, defining the incident influence area boundaries as linear will be an approximation of the real traffic conditions in which distortions of the system response such as platoon dispersion, lane-changing and car-following behavior are greatly idealized. The pattern recognition algorithm on the other hand accounts for variation within the development of high occupancy area with respect to the incident location and is limited only to the time and distance slices widths. Moreover, with the increase in the accuracy of shock wave boundaries the quality of secondary incidents estimation should also increase. In Figure 6-2 differences between a classical analytical approach using the shock wave theory and the actual mapping of the occupancy values are detailed.

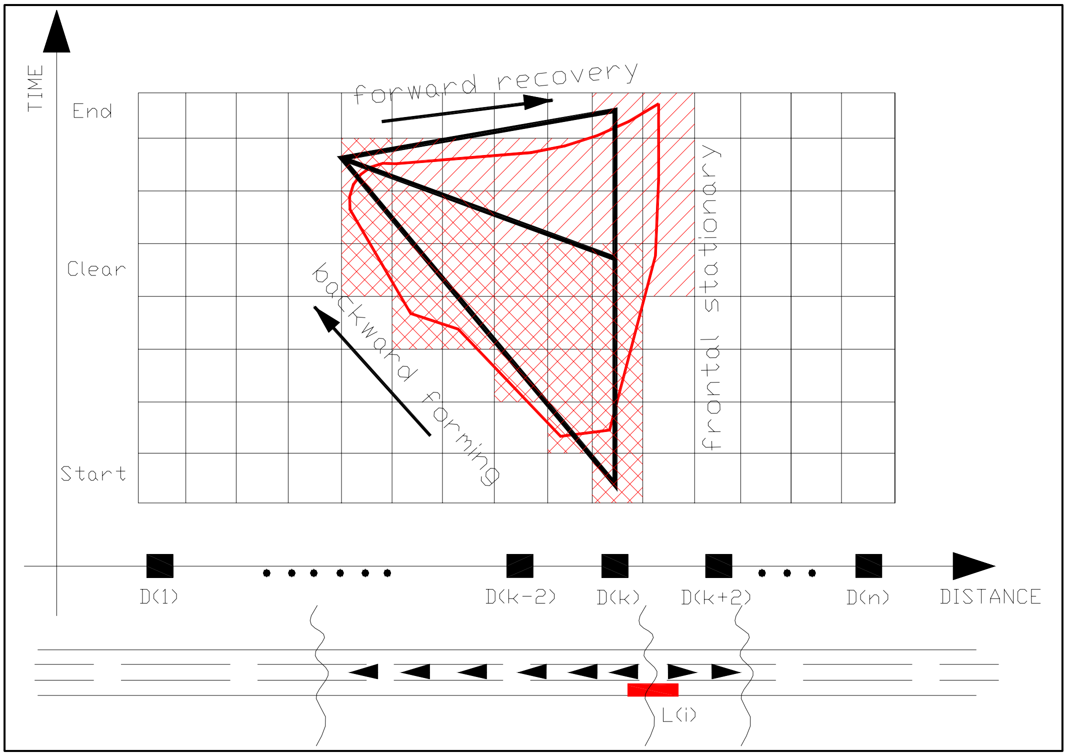


Figure 6-2 Shock Wave Differences between Analytical and Loop Detector Methodology

Since shock wave development was considered to be nonlinear, in order to facilitate the analysis, the occupancy domain area was approximated using piece-wise slices. In defining the slices width a trade-off between the accuracy of the results and the output manipulation effort had to be achieved. In terms of occupancy maps distance slices a high detector frequency replicate detectors was designed each of the two directions of I287 model having a number of 38 cross sectional stations resulting in a frequency of approximately three per mile. The pooling capacity of the detectors defining the time slices accuracy was considered to be 10 minutes. With the time and space slices defined that way, the model has the capability to capture most shock wave developments with speeds starting at a very low value (stop and go conditions).

With the occupancy output design set, the analysis of the secondary incidents becomes nothing more than a geometrical exercise of determining the extent of the feasible region. The hypothetical correlation between the secondary incidents likelihood and the primary incidents is examined using the time-space evolution of disturbance boundaries while considering only the impact of isolated incidents (Figure 6-3).

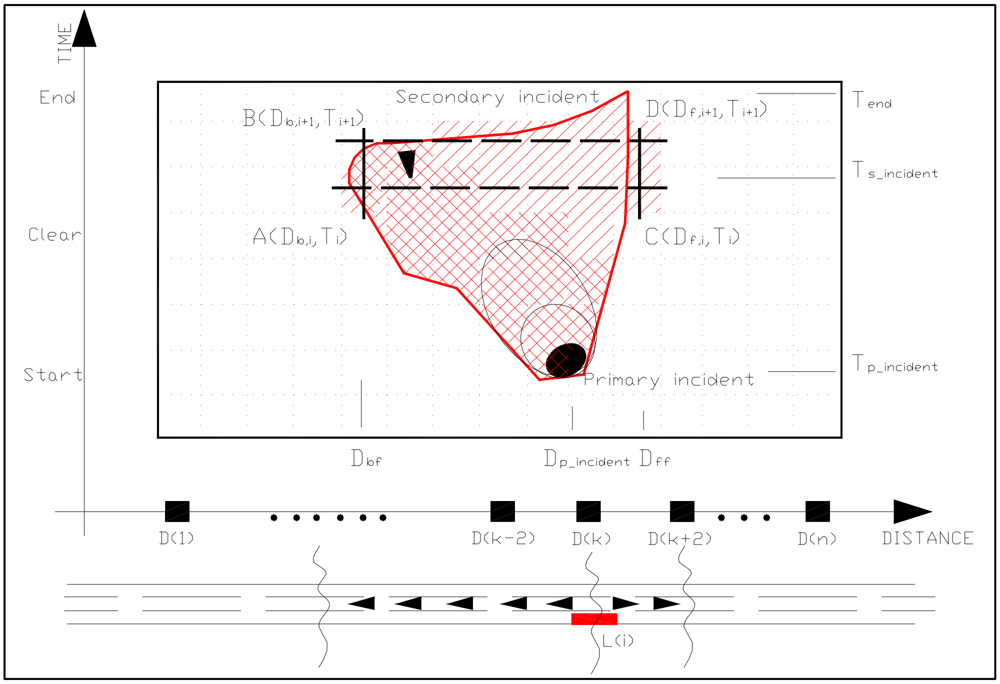


Figure 6-3 Secondary Incidents Feasibility Area

The notations of Figure 5-5 are divided in the following two categories:

A) *Defining attributes of the general feasibility area*

- $D_{p\_incident}$ – longitudinal location of the primary incident
- $D_{s,incident}$ – longitudinal location of the secondary incident
- D_{ff} – longitudinal limit of the forward forming shock wave
- D_{bf} – longitudinal limit of the backward forming shock wave
- $T_{p, incident}$ - incident detection time
- T_{s}, $_{incident}$ –secondary incident detection time
- T_{end} – complete recovery time (missing)

B) Defining attributes of the secondary incident specific boundaries

- $D_{b,i}$; $D_{b,i+1}$ – rear feasibility area boundaries for the "i" and "i+1" time slices
- $D_{f,i}$; $D_{f,i+1}$ – frontal feasibility area boundaries for the "i" and "i+1" time slices
- T_i, T_{i+1}, D_k, D_{k+1} – data pooling time and detector locations

Using the above notations, the problem of determining the secondary incidents reduces to a geometrical exploratory analysis which seeks to find whether the shock waves contingency creates satisfactory conditions to propagation of incidents either downstream or upstream of the primary disturbance, and in the same direction. Finding out if a driver was "at the wrong time and at the wrong moment" requires several filtering procedures which will be summarized in the following paragraphs.

Assuming the secondary incidents occur between the "i" and "i+1" time slices, a fact that can be easily determined using the incident data logs, and the pooling frequency of detectors, the two dimensional search procedure on the secondary incident presence reduces to a single one. Therefore, simple equations describing a linear piece-wise approximation of the shock wave in that area can be implemented. Equations 6-3 and 6-4 and system of inequalities 6-5 completely describe the space boundaries such that an incident will be considered secondary.

$$X_b = (T_{s,incident} - T_i) \cdot \frac{D_{b,i+1} - D_{b,i}}{T_{i+1} - T_i} + D_{b,i} \qquad [6\text{-}3]$$

$$X_f = (T_{s,incident} - T_i) \cdot \frac{D_{f,i+1} - D_{f,i}}{T_{i+1} - T_i} + D_{f,i} \qquad [6\text{-}4]$$

→*Solve for*: X_b and X_f or the rear and the frontal boundaries of the congested area corresponding to the [i, i+1] time interval.

$$\begin{cases} X_b \geq D_{s,incident} \\ X_f \leq D_{s,incident} \end{cases} \qquad [6\text{-}5]$$

Chapter 7. SENSITIVITY ANALYSIS RESULTS

The main scope of the current research was to explore the optimum deployment of H.E.L.P. program by addressing the relation between the cost-effectiveness of I-287 study area (expressed as benefit cost ratios) and variability of prevailing traffic conditions. Using the Multi Layer Sensitivity Analysis scenarios defined in Chapter 5, the first four sections of the current chapter will address the specific procedures used to determine the monetary values of program benefits (delay, fuel and emissions, secondary incidents), and costs when the output of CORSIM H.E.L.P. simulation model is already available. The last section will summarize the cost-effectiveness of H.E.L.P. program in terms of a panel of benefit cost ratios indicating the warranted traffic conditions for H.E.L.P. deployment.

7.1. Delay Reduction and the Value of Time

As a first measure of evaluating the cost effectiveness of H.E.L.P. operations, CORSIM output in terms of delay was considered. Methodologically, CORSIM delay for a link results from computing the difference between the resulted total travel time and free-flow travel time on that link, with the total travel time continuously updated to account for each vehicle release from that link. Therefore, CORSIM measure for freeway delay is complete in the sense that microsimulation computations take into account both moving and queuing delay.

For a specific scenario of the Multi Layer Sensitivity Analysis ($\mathbf{S}_{\Re}\,(\mathbf{I};\, f\,(\mathbf{v},\, \mathbf{d},\, \mathbf{r}))$ - corresponding to a level of service and incident capacity reduction), the total delay was computed as a summation of individual incident delays. Still, for the ease of reference results are presented in terms of the average delay reduction [veh-hours] when H.E.L.P operations reduce the total incidents time with 5, 10, 15, and 20 minutes on average (Table 6-1). For example, the results of delays reduction analysis indicate that for a LOS D and a 5% incident capacity reduction, an average decrease of 5 minutes in total incidents time translates into a delay saving of 14.50 [veh-h]/ incident. Similarly, for a LOS B and the same incident capacity reduction an average decrease of 5 minutes in the total incidents time translates into a much smaller delay saving – 0.77 [veh-h] /incident. Also total delay values can be easily obtained by multiplying the results of Table 7-1 with the number of incidents serviced by H.E.L.P. operations (155).

Level of service	**Incident capacity reduction [%]**	**Delay reduction [veh-h] / incident for total incident time reduction =**			
		5 min	**10 min**	**15 min**	**20 min**
B	**5**	0.77	1.38	1.93	2.36
B	**10**	0.75	1.43	2.02	2.45
B	**15**	0.74	1.38	1.93	2.39
B	**25**	0.72	1.38	1.96	2.42
B	**30**	0.78	1.50	2.06	2.56
B	**35**	0.92	1.66	2.34	2.88
C	**5**	2.28	4.46	6.54	8.44
C	**10**	2.51	4.84	7.13	9.15
C	**15**	2.74	5.27	7.82	10.15
C	**25**	3.04	6.10	8.90	11.45
C	**30**	4.20	8.53	12.55	16.47
C	**35**	5.52	11.16	16.61	21.88
D	**5**	14.50	28.83	43.64	57.55
D	**10**	15.64	32.17	48.72	64.11
D	**15**	30.72	61.62	93.40	124.47
D	**25**	34.48	69.80	105.04	138.70
D	**30**	47.52	97.42	147.62	195.96
D	**35**	53.62	108.32	163.46	213.75

Table 7-1 H.E.L.P Delay Reduction Rates

In order to compute the monetary equivalent of delay savings, the Hudson Valley value of time (VOT) must be estimated. With national estimates varying between $ 10 per hour to over $ 100 per hour, the unit travel time value (VOT) will be a combination of commuter's travel time value, and single units and combinations trucks operators travel time value. Still, since H.E.L.P. operating hours on the I-287 study area experience low percentages in terms of the last two categories (peak hour maximum truck percentage = 4%), their influence in terms of value of time will be negligible. Moreover, since a comprehensive estimation of the VOT will require knowledge about commuter's income structure, and length and purpose of trips[3], a simplified method was applied.

Latoski (1998) estimated the VOT using the AAA reference on commuter's value of time ($6) and the Highway Economics Requirement System reference on trucks value of time ($26.87) as a basis for CPI calculations. Using the same rationale, and considering the percentage of trucks and commuters Hudson Valley VOT is $11.62 for the lowest percentage of trucks (4%) and $16.31 for the highest percentage of trucks (20%). As a result of CPI computations, **a $15 value** was considered to be conservative enough to be used for delay benefit computations, and representative for a traffic mix dominated by automobiles.

7.2. Emissions and Fuel Consumption Reduction

Both emissions and fuel consumption are evaluated in CORSIM by means of tracking vehicular movement performance on a second-by-second basis. For each of

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[3] Typical calculations are based on wages or total compensation. With trips divided into on the job and outside the job, a weighted value of travel time will result from considering the cost of the employee on one hand and the fringe benefits on the other hand.

the nine types of vehicles and depending on the current speed and acceleration CORSIM provides a correspondent value of the fuel and emissions rate based on standardized tables. This relationship has been empirically developed by experiments conducted between 1980 and 1995 at Oak Ridge National Laboratory (ORNL) and resulted in lookup tables that relate fuel consumption and CO, HC and NO_x hot stabilized emissions as a function of travel speed and acceleration. The range of velocities included in the current tables is between 0 and 110 feet per second (0 to 75 mph) with acceleration levels of ±9 feet/sec^2 (±7 mph/sec).

The aggregated fuel consumption data reveals differences from the delay patterns having values which depend not only in the level of service, incident capacity reduction and total incident time reduction (Table 7-2).

Level of service	**Incident capacity reduction [%]**	**Fuel reduction [gallons] / incident for total incident time reduction =**			
		5 min	**10 min**	**15 min**	**20 min**
B	**5**	0.52	0.00	0.71	0.27
B	**10**	0.10	0.00	0.00	0.00
B	**15**	0.00	0.00	0.00	0.00
B	**25**	0.48	0.95	1.70	1.61
B	**30**	0.65	0.61	0.63	1.08
B	**35**	0.00	0.00	0.00	0.00
C	**5**	1.42	2.05	4.20	5.12
C	**10**	0.33	3.06	3.74	5.52
C	**15**	2.04	4.34	6.07	7.22
C	**25**	1.64	5.31	5.45	6.89
C	**30**	3.62	9.05	13.03	15.23
C	**35**	5.21	10.76	14.03	18.91
D	**5**	19.03	37.32	54.17	67.89
D	**10**	17.59	36.23	53.29	66.52
D	**15**	38.14	70.37	98.24	122.21
D	**25**	33.33	63.68	86.63	102.93
D	**30**	49.62	92.06	128.75	155.68
D	**35**	44.55	82.00	109.91	118.27

Table 7-2 H.E.L.P Fuel Reduction Rates

HC, CO and NO emissions values are reported in Table 7-3, 7-4 and 7-5 as kg / incident. In order to compute their value, emissions rates reported by CORSIM as grams/mile were multiplied with the maximum traffic volumes for each scenario and I-287 length and the result was divided by number of incidents and transformed into kilograms.

Level of service	Incident capacity reduction [%]	HC emissions reduction [kg] /incident for incident total time reduction =			
		5 min	10 min	15 min	20 min
B	**5**	0.00	0.00	0.00	0.00
B	**10**	0.07	0.00	0.15	0.27
B	**15**	0.00	0.00	0.00	0.00
B	**25**	0.00	0.00	0.00	0.00
B	**30**	0.07	0.15	0.31	0.17
B	**35**	0.04	0.19	0.15	0.60
C	**5**	0.05	0.23	0.51	0.41
C	**10**	0.20	0.40	0.67	0.51
C	**15**	0.02	0.00	0.04	0.67
C	**25**	0.02	0.71	0.76	1.19
C	**30**	0.13	0.43	1.07	1.34
C	**35**	0.69	0.98	1.56	2.17
D	**5**	1.23	2.23	3.31	4.43
D	**10**	1.57	2.80	4.14	5.31
D	**15**	2.10	4.36	6.38	8.24
D	**25**	2.74	5.35	7.34	9.66
D	**30**	2.57	5.61	8.28	10.98
D	**35**	3.50	6.99	10.05	11.93

Table 7-3 H.E.L.P HC Emissions Reduction Rates

Level of service	Incident capacity reduction [%]	CO emissions reduction[kg] /incident for incident total time reduction =			
		5 min	10 min	15 min	20 min
B	5	0.00	0	0.00	0.00
B	10	1.57	0	2.55	4.50
B	15	0.00	0	0.00	0.00
B	25	0.00	0	0.00	0.00
B	30	0.85	2.64	4.89	3.38
B	35	1.54	3.98	3.37	11.13
C	5	0.00	0	0.00	0.00
C	10	3.27	5.00	10.46	7.61
C	15	0.00	0	0.00	0.00
C	25	0.00	0	0.00	0.00
C	30	0.45	5.74	15.39	19.81
C	35	11.45	16.34	24.49	33.95
D	5	18.96	31.86	45.25	60.47
D	10	23.73	40.15	58.29	73.94
D	15	28.28	58.03	80.61	101.79
D	25	38.38	72.16	94.13	120.29
D	30	29.76	65.22	91.22	119.97
D	35	44.36	86.31	119.03	126.66

Table 7-4 H.E.L.P CO Emissions Reduction Rates

Level of service	Incident capacity reduction [%]	NO emissions reduction [kg] /incident for incident total time reduction =			
		5 min	10 min	15 min	20 min
B	5	0.00	0.00	0.00	0.00
B	10	0.06	0.00	0.12	0.37
B	15	0.00	0.00	0.00	0.00
B	25	0.00	0.00	0.00	0.00
B	30	0.05	0.27	0.61	0.16
B	35	0.00	0.00	0.00	0.00
C	5	0.30	0.43	1.21	0.99
C	10	0.00	0.00	0.00	0.00
C	15	0.22	0.00	0.00	1.40
C	25	0.00	0.00	0.00	0.00
C	30	0.19	0.73	2.31	2.78
C	35	1.33	1.78	3.00	4.33
D	5	2.59	4.90	7.20	9.61
D	10	3.63	6.32	9.32	11.77
D	15	4.55	9.04	13.01	16.46
D	25	5.73	10.92	14.52	18.84
D	30	4.81	10.43	14.93	19.24
D	35	6.49	12.49	17.49	19.17

Table 7-5 H.E.L.P NO Emissions Reduction Rates

Inconsistencies of Tables 7-2, 7-3, 7-4, and 7-5 can be attributed to the fact that both emissions and fuel consumption rates are constructed based on the acceleration and deceleration rates, both parameters describing the aspects related to the behavioral characteristics of traffic flow much more in detail then the purpose of this research. Induced variability of these results can be attributed to the transient state of the traffic flow and/or insufficient multiple runs.

While the June fuel price value had a straightforward value of \$2 / gallons, emissions monetary equivalents are generally harder to quantify. Out of previous studies on cost-effectiveness of freeway service patrols the only one which detailed the emissions benefits as monetary values was Maryland DOT CHART program with rates of \$6,700 /ton for HC, \$6,360/ton for Co and \$12,875/ton for NO (Chang and Point-Du-Jour, 2001. Still, in reporting the emission results the choice was to maintain the kilograms format. The main reason for excluding the emissions impact is induced by the difficulty in attributing a monetary value to the resulted rates. In contrast with the delay and fuel consumption, emissions information would have to be evaluated in the more comprehensive frame of the impacted area which requires considerations related to the atmospheric dispersion of the emissions and the population at risk.

7.3. **Reduction in Total Number of Secondary Incidents**

In describing the secondary incident formation the objective was to provide reasonable evidence on the evolution of number of secondary incidents for different traffic scenarios. In order to achieve this objective, we considered shock-wave formation to be a representative feasible area for the secondary incidents occurrence and filtered the incidents accordingly. The filtering procedure described in Chapter 5 considered each of the 155 incidents serviced by H.E.L.P. operations as a primary one, and based on the shock-wave formation induced by the existing traffic conditions searched the entire incident database for secondary incidents (346 incidents).

Still, one has to distinguish between the intuition behind the results of the current methodology and the actual formation of secondary incidents. Ideally, this relation between shock-wave information and secondary incident formation should also be validated using field information. Therefore for the data set provided, we explored the incident information in terms of two way thruway narratives, HTE-CAD logs and ATMS to find any descriptors defining the degree of congestion when incidents occurred. Unfortunately none of the mentioned databases provides relevant information to reveal whether the secondary incidents procedure is valid or not, a fact that will generate an inherent degree of fuzziness of results. While we recommend adjustments in future data collection process in terms of providing descriptions on travel times by means of probe vehicles and/or more dense loop-detector data, in the following paragraphs we present the results of the proposed procedure.

Table 7-6 presents the results in terms of the reduction of secondary incidents for different scenarios when the threshold for defining congested conditions was considered the mean occupancy rate of 28%. The results indicate that for example, a 10 minute incident reduction for LOS D when capacity is reduced by 10% eliminates two possible secondary incidents.

Level of service	Incident capacity reduction [%]	Secondary incidents reduction for incident total time reduction = 5 min	10 min	15 min	20 min
B	**5**				
B	**10**				
B	**15**				
B	**25**				
B	**30**				
B	**35**				
C	**5**				
C	**10**				
C	**15**				
C	**25**				
C	**30**			1	1
C	**35**				
D	**5**	1	1	3	3
D	**10**		2	1	3
D	**15**		1	2	3
D	**25**	1	1	2	5
D	**30**	1	4	6	6
D	**35**			2	2

Table 7-6 H.E.L.P. Secondary Incidents Reduction

It is easy to observe that implementing the H.E.L.P. program proves to be extremely beneficial for the secondary incidents reduction only for scenarios which are defined by traffic volumes close to saturation values (LOS D). The results are generally consistent with the expected trends of incident queue formation (increase of secondary incidents reduction with increase in total incident time reduction) with the exception of Scenario (LOS D, 10).

In this case although not large (1 incident) an “abnormal” fluctuation on the reduction of secondary incidents is registered by the proposed occupancy detection method. The main reason is that the current methodology is designed to address the entire set of shock waves boundaries, even more rare events such as forward forming shock waves (moving with the traffic direction). The fluctuations resulted in the secondary incident reduction are the result of a forward forming shock wave on the incident recovery stage of a scenario with a total incident duration of t1 which is not retrievable by the correspondent backward shock wave formation in the scenario with a total incident duration of t2 (t2>t1) . In other words, considering the same potential secondary incident time we might conclude or not on its presence in the feasible region according to the primary incident stage (either recovery or queue formation).

In terms of secondary incidents the implemented procedure resulted in consistent results with the findings of Giuliano (2004) which reports a rate between 0.007 and 0.013 of secondary accidents per number of incidents. In terms of secondary incident reduction across all scenarios, the presence of H.E.L.P. eliminates approximately 12% for a 5 minutes reduction in total incident time, 25% for a 10 minutes reduction in total incident time, 43% for a 15 minutes reduction in total incident time and 50% for a 20 minutes reduction in total incident time.

Moreover, using a second filtering procedure using the difference in time and space of secondary incidents from primary incidents the relation between the occurrence of secondary incidents and their feasibility area was explored. Total number of secondary incidents across all scenarios for “with” H.E.L.P. operations, and “without” H.E.L.P operations (5, 10, 15, 20 minutes increase in total incident time) disaggregated for different values of time and space proximity are presented in Appendix B. The graphs of Appendix B are consistent in revealing the fact that relative to the feasibility area determined by the shock wave formation, the large majority of secondary incidents (**more then 70%**) occur within 1 at most 2 hours of primary incidents, and are located in the proximity of primary incidents (within one mile). Still, due to the small number of available incidents[4] these findings should be considered preliminary.

Secondary incident findings reveal two aspects which can be implemented as further refinements to the existent model. The first one is that the current method as it is designed right now is not well suited for the evaluation of the correlation between multiple incidents occurring in proximity and time and space. The second one is that only the difference in secondary incidents between the base case and the considered scenario might be misleading if no information on the congestion level is available.

After emissions cost, the monetary benefit of reducing one secondary incident is another measure of performance subject to interpretations. After exploring the characteristics of primary-secondary pairs all secondary incidents were assimilated with property damages (AA-PDO). Latoski (1998) used the National Highway Safety Administration reported value of $ 1,351 for PDO's (1994), a value that adjusted using the Hudson Valley CPI indexes results in a value of **$ 1,706**.

7.4. H.E.L.P. Program Costs

In terms of the cost evaluation procedure, two parameters were of interest and relate to the way in which the FSP service is provided and the considered value of travel time. With respect to the H.E.L.P Program the complexity of the cost evaluation procedure was greatly reduced by the existence of a predefined bid process in which the contractors were asked to indicate an hourly rate which will include the full extent of their expenses. According to data provided by the New York State Department of Transportation, the cost of operating the freeway service patrol trucks

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[4] In a similar study Giulliano (2004) have a database of 6,619 (only accidents)

can be represented by an approximate value of \$ 50/ truck hour. This information combined with the number of roving trucks (2) and total number of working hours (23 days x 8 hours) was used to determine the total cost of H.E.L.P. deployment in the I-287 study area.

7.5. **Cost Effectiveness of H.E.L.P. Program**

With respect to the above measures of effectiveness the monetary evaluation of the benefits of H.E.L.P. deployment on I-287 was restricted to delay, fuel consumption and secondary incidents reduction. The main reason for excluding the emissions impact is induced by the difficulty in attributing a monetary value to the resulted rates. In contrast with the delay and fuel consumption reduction, emissions reduction benefit has to be evaluated in a more comprehensive framework considering the characteristics of the atmospheric dispersion of the emissions and the population at risk. The total benefit for a specific scenario S $_{\text{(LOS, capacity reduction)}}$ will be computed using Equation [7-1]. Also, the results are presented in Table 7-7.

$$TB_S = N(d \cdot VOT + f \cdot FP) + N_{\sec} \cdot CS \qquad [7\text{-}1]$$

Where:

- TB_s = total benefit of scenarios S [\$]
- N =number of incidents serviced by H.E.L.P. (155)
- N_{sec} = number of secondary incidents for scenario S
- d = reduction delay rate [veh-h/ incident] – table 6-1
- f = fuel reduction rate [gallons/incident] –table 6-2
- VOT = value of time (\$ 15)
- FP = fuel price (\$ 2)
- CS = cost of secondary incident (\$ 1,706)

Table 7-7 presents the resulted benefit cost ratios with efficient frontier of cost-effective operations described by the upper bound of the shaded area.

Level of service	Incident capacity reduction [%]	Benefit Cost Ratios for incident total time reduction =			
		5 min	10 min	15 min	20 min
B	**5**	0.10	0.17	0.25	0.30
B	**10**	0.10	0.18	0.25	0.31
B	**15**	0.09	0.17	0.24	0.30
B	**25**	0.10	0.18	0.26	0.32
B	**30**	0.10	0.19	0.27	0.33
B	**35**	0.12	0.21	0.30	0.36
C	**5**	0.30	0.58	0.86	1.11
C	**10**	0.32	0.64	0.93	1.20
C	**15**	0.36	0.70	1.04	1.34
C	**25**	0.40	0.82	1.17	1.50
C	**30**	0.56	1.15	1.79	2.30
C	**35**	0.74	1.50	2.22	2.92
D	**5**	2.09	4.05	6.25	8.12
D	**10**	2.12	4.56	6.70	8.94
D	**15**	4.20	8.47	12.81	17.04
D	**25**	4.73	9.45	14.19	18.86
D	**30**	6.52	13.46	20.29	26.63
D	**35**	7.15	14.38	21.77	28.19

Table 7-7 Benefit Cost Ratios of H.E.L.P. Program

The results indicates that under low traffic conditions (LOS B which is equivalent with volumes <1000 pcphpl) H.E.L.P operations defined by incidents total time reduction of 5 to 20 minutes and values of incidents capacity reduction of 5% to 35% are not cost effective when compared with the situation without H.E.L.P. This situation changes for medium traffic conditions but only for those circumstances which are below the efficient frontier. Finally, for high traffic conditions the deployment of H.E.L.P. trucks is cost effective for all the possible operating scenarios.

In order to provide a single measure of benefit-cost ratios for each value of incidents total time reduction, the efficient values were averaged for values of traffic >1500 pcphpl resulting in a value of B/C ratio of **2.46 for 5 minutes incident time reduction, 4.98 for 10 minutes incident time reduction, 7.50 for 15 minutes incident time reduction, and 9.85 for 20 minutes incident time reduction**. Provided that traffic operating conditions are within boundaries of cost-efficiency defined by Table 6-7, the benefit cost ratios analysis of H.E.L.P operations indicates that the program is extremely beneficial and it should be continued.

Chapter 8. **CONCLUSIONS AND FURTHER RESEARCH**

8.1. Summary of Research Results

The main objective of the current research was to estimate the cost-effectiveness of H.E.L.P. program using available data on a portion of I-287 highway (between I-95 Corridor and Tappan Bridge). As a general background on H.E.L.P.'s operations an overview of program characteristics in terms of incident distribution, detection efficiency, clearance and response time, and number of secondary incidents was first detailed.

The results indicated that H.E.L.P. operations have a significant impact on incident detection process (50% of total number of serviced incidents), while maintaining the reduction of incident total time within a 20 minutes interval. Also, the large majority of H.E.L.P. response times (80%) are within program's stated objective of 10 minutes, while less then half of clearance times (40%) are less then the program's stated objective of 15 minutes. These results stress the importance of H.E.L.P patrols in terms of incident detection process while constraining their clearance activities to incidents of low severity (addressable within a 15 minutes interval). Another element which underlines the importance of H.E.L.P is the distribution of different incident types. The results of the analysis indicate the substantial decrease in percentage of debris and abandoned vehicles when H.E.L.P. operates as compared to weekend periods (from 8.70% to 1.94% and from 41.30% to 23.33%). Finally, a filtering procedure on the number of secondary incidents was designed to address the variability of estimation when secondary incidents are defined only by the proximity in time and space from a primary incident.

In order to motivate the current research approach, a literature review of the most relevant Freeway Service Patrol studies was presented. With majority of studies focused towards statistical interpretation of data as main method to determine FSP program's effectiveness, notable differences are represented by California FSP, Indiana Hossier Helper and Maryland CHART programs. While all the aforementioned studies have used B/C ratios to describe program cost effectiveness, none has considered the impact of variation in prevailing traffic conditions on these ratios. Therefore, the current study uniqueness lies in addressing the cost effectiveness evaluation from a perspective that will permit inferences on the optimum deployment of H.E.L.P. patrols with respect to different traffic conditions.

In order to model this variability of prevailing traffic conditions one of the most popular traffic micro-simulation software packages (CORSIM) was used to define a model capable to accommodate H.E.L.P. operations in a conservative way (lower bound). Furthermore, using a Multi Layer Sensitivity Analysis (MLSA) function of traffic volumes, rubberneck factor and driver aggressiveness 18 traffic scenarios were defined and their output analyzed with respect to different levels of incidents total time reduction (5, 10, 15 and 20 minutes). In the context of nation wide freeway service patrols operation conditions, MLSA parameters domain was justified and simplified to accommodate more tractable parameters such as Level of Service and Incident Capacity Reduction. With the structure of the MLSA set, the simulation output defined by the reduction in delay (veh-h / incident), fuel consumption (gallons / incident), HC, CO, NO emissions (kg/incident) and secondary incidents was used to determine program benefits for a considered scenario.

The result in terms of the Benefit Cost ratio indicate that for segments which are similar to the study area H.E.L.P. implementation is recommended only for volumes values greater then 1500 pcphpl (LOS C). Depending on the set of parameters considered the B/C ratios will vary covering the set of values provided by Fenno (1998) survey. However for traffic volumes with values greater then 1500 pcphpl and considering results of Table 7-7 the H.E.L.P program proves to be extremely cost-effective with benefit cost ratios ranging from **4.47** for 5 minutes incident time reduction, to **9.85** for 20 minutes incident time reduction. A detailed presentation of H.E.L.P. methodology and results when compared with similar programs such as FSP, HELPER and CHART is presented in Appendix A.

8.2. Recommendations for Future Research

Although the current methodology was constructed on the characteristics of the Highway Emergency Local Patrol (HELP) the framework is designed to permit the extension of the findings to similar freeway service patrols. One important observation pertaining to the applicability of this study is that instead of focusing on the operational aspects of the program (fleet, coverage, hub location and frequency of service) in order to achieve an optimum desired configuration it takes a different approach by considering the variability of the traffic conditions within the existing program. Therefore, the main objective of the analysis was focused towards the cost-effectiveness estimation rather then the optimization of the present design.

With respect to the current methodology, in order to have a nation-wide comprehensive procedure two more tasks are required and will be included as directions of future research. As a first task the development of robust procedures to account for incident reduction, delay, fuel consumption and emissions when considering multiple incidents is highly desired. Robustness will ultimately translate in estimating the B/C ratios when considering road sectors having different geometric configurations, with incident data breakdown by seasons but also in precise evidence of freeway service patrols “with” and “without” operations.

Finally, in order to validate model assumptions in terms of secondary incidents, the impact of H.E.L.P. trucks operations on the evolution of traffic conditions has to be empirically reinforced, using either probe vehicles or denser loop detectors data. The evidence of real-world data in terms of travel times and densities should provide a better dissemination of the proposed H.E.L.P. CORSIM incident model and better isolate the cost-effectiveness of freeway service patrols, currently detailed only as a lower bound.

Appendix A

	FSP	**HELPER**	**CHART**	**H.E.L.P.**
Year of data	1994	1995-1996	1997	2004
Study area	9.2 miles /I-880	Network	Network	10.2 miles / I-287
Study period	Before = 24 week days After = *23 week days*	day time = 12 months all day = 7 months	Full year	30 days (week and weekend)
Method	“before”/“after”	“with”/“without”	“with”/ “without”	“with”/ “without”
Incident Time Reduction	breakdowns 16.5 minutes Accidents 12.6 minutes	10 minutes	N/A	5 minutes 10 minutes 15 minutes 20 minutes
Delay	breakdowns 42.36 veh-h/inc breakdowns 20.32 veh /inc	N/A[*]	N/A	Variable (Table 6-1)
Value of time (VOT)	$10	$14.88 week $11.76 weekend	$14.34	$15
Fuel	31 gallons/ assist	N/A*	8.6 million gallons	Variable (table 6-2)
Gas Price	$1.15	N/A*	$1.00	$2.00
Emissions	3.51 kg HC /assist 35.84 kg CO /assist 8.85 kg NO /assist	N/A	427.96 tons HC 3532.5 tons CO 1684 tons NO	variable (Tables 6-3, 6-4, 6-5)
Emission cost	N/A	N/A	$6,700 / ton HC $6,360 / ton CO $12,875 / ton NO	N/A
Secondary Incidents	N/A	Variable /season	1344	Variable (Table 6-6)
Secondary Incidents Cost	N/A	$ 1,351 (PDO)	N/A	$1,706
Hour-truck Cost	$72.36	$ 55	N/A	$50
B/C	**3.35**	Day time **4.71** All day **13.28**	N/A	**2.46** –for 5 minutes **4.98** – for 10 minutes **7.50** –for 15 minutes **9.85** for 20 minutes

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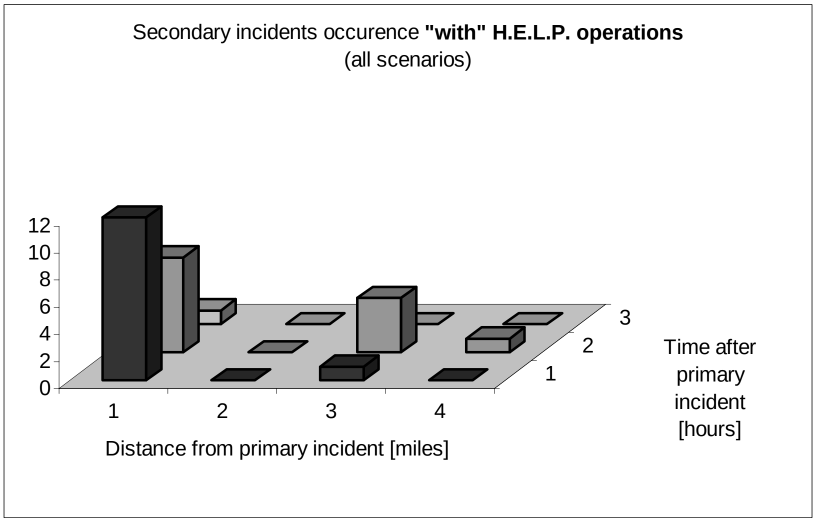
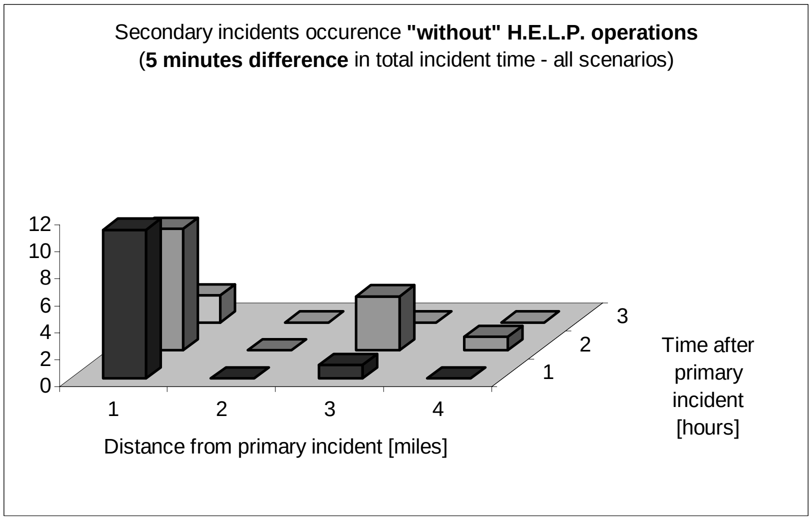
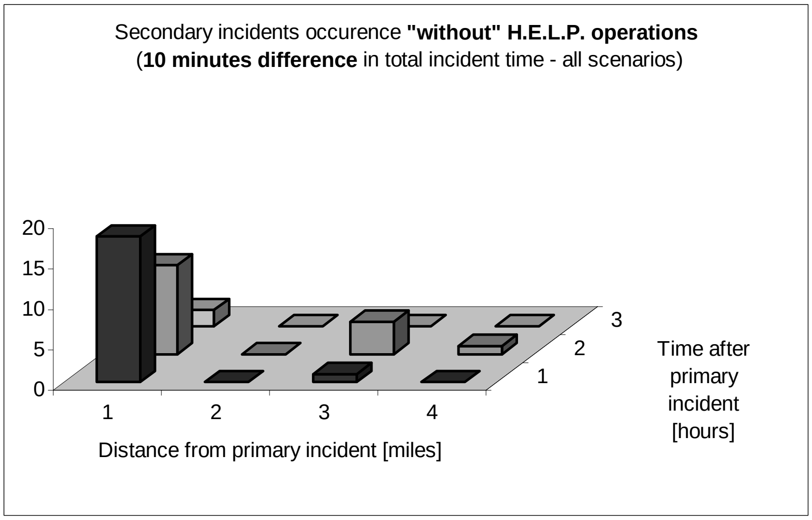
[*] Non recurrent delay was generated with the help of a designed macroscopic model XXEXQ

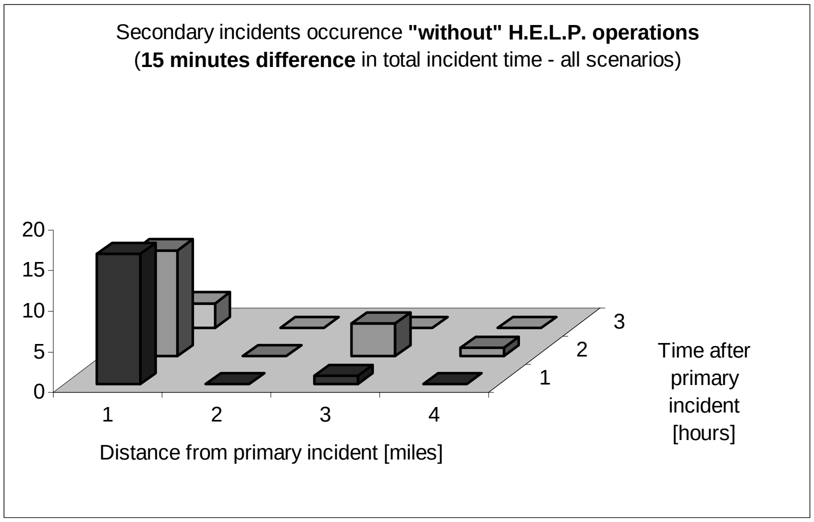
Appendix B


Secondary incidents occurence **"with" H.E.L.P. operations**
(all scenarios)
12
10
8
6
4
2
0
1
2
3
4
Distance from primary incident [miles]
3
2
1
Time after primary incident [hours]

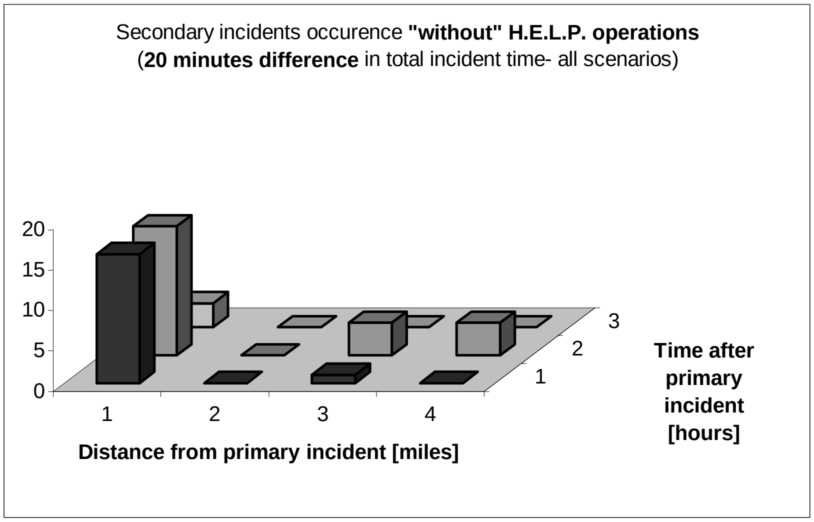

Secondary incidents occurence **"without" H.E.L.P. operations**
(**5 minutes difference** in total incident time - all scenarios)
12
10
8
6
4
2
0
1
2
3
4
Distance from primary incident [miles]
3
2
1
Time after primary incident [hours]


Secondary incidents occurence **"without" H.E.L.P. operations**
(**10 minutes difference** in total incident time - all scenarios)
20
15
10
5
0
1
2
3
4
Distance from primary incident [miles]
3
2
1
Time after primary incident [hours]

Appendix B



Secondary incidents occurence **"without" H.E.L.P. operations**
(**15 minutes difference** in total incident time - all scenarios)
20
15
10
5
0
1
2
3
4
Distance from primary incident [miles]
3
2
1
Time after primary incident [hours]



Secondary incidents occurence **"without" H.E.L.P. operations**
(**20 minutes difference** in total incident time- all scenarios)
20
15
10
5
0
1
2
3
4
Distance from primary incident [miles]
3
2
1
Time after primary incident [hours]

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