USDOT Region V Regional University Transportation Center Final Report

NEXTRANS Project No. 074WY03

Investigation of Freeway Operations in Metro Detroit

By

Dr. Peter T. Savolainen
Assistant Professor
Wayne State University
Department of Civil and Environmental Engineering
Detroit, Michigan 48202
Email: savolainen@wayne.edu

and

Dr. Indrajit Ghosh
Visiting Faculty
Transportation Engineering Group
Department of Civil Engineering
Birla Institute of Technology and Science Pilani
Vidya Vihar Campus
Pilani, Rajasthan 333031
India
Email: i.ghosh@bits-pilani.ac.in

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USDOT Region V Regional University Transportation Center Final Report

TECHNICAL SUMMARY

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Investigation of Freeway Operations in Metro Detroit

Introduction

Traffic incidents are the primary cause of non-recurrent congestion in urban areas, resulting in reductions in roadway capacity due to crashes, vehicle breakdowns, and other events. In addition to contributing to congestion and delay, incidents can result in significant safety hazards to other motorists, as well as first responders. In response to these adverse impacts, many communities have initiated incident management programs that detect and respond to incidents and restore freeways to full capacity by clearing the incident scene as soon as possible. Such programs play an important role in the operation of the transportation system and require collaboration and efficient communication among various agencies, including fire and rescue, police, towing and recovery, transportation engineers, and freeway service patrols. In the Detroit metropolitan area, the Michigan Department of Transportation (MDOT) operates a Freeway Courtesy Patrol (FCP) program as part of its larger freeway incident management program from the Michigan Intelligent Transportation Systems (MITS) Center in downtown Detroit.

The MITS Center maintains a series of databases that detail freeway operations, as well as the activities of the FCP. This report details the activities from the second year of a two-year study aimed at assessing freeway operations in metropolitan Detroit. During the first year of this study, a software interface was developed to combine data from these various sources. These data include traffic flow information obtained from roadside microwave sensors, incident response data collected by FCP operators, and roadway geometry data. This research involves the development of a series of duration models to assess how various factors affecting the time required to clear freeway incidents. Various model formulations are compared and the transferability of model results across freeway segments is assessed.

Findings

Four model formulations were examined, each assuming a different underlying distribution for the hazard function. The results showed the log-logistic distribution to provide the best fit for the incident clearance data in comparison to other parametric models, though each of the models produced consistent parameter estimates.

Shorter clearance times were observed during weekends and the morning shift on weekdays when volumes were lower. Several other volume-related factors were also shown to have significant impacts, including the route on which the incident occurred, the 85th percentile speed on the segment, and the variability in speeds as measured by the difference between the 15th and 85th percentile speeds. Clearance times were longer during the winter months, when incidents impacted adjacent traffic or required the closure of travel lanes, on segments with horizontal curves, or where no exit ramps were available for motorists or FCP responders.

Recommendations

This study showed that hazard-based duration models provide an appropriate tool for assessing incident durations. The findings from these models can be used to more efficiently manage the incident clearance process. Additionally, these models may be used in the future to assess changes in incident management performance over time or to estimate the potential impacts of policy changes. While the effects of the aforementioned factors on incident clearance times were relatively consistent across freeways, a likelihood ratio test showed that the freeway-specific models provided superior performance to a single, joint model. Subsequent research may examine the utility of other, more flexible statistical models that allow for heterogeneous effects both within and across freeway segments. The temporal transferability of these models could also be assessed to determine how the impacts of relevant factors may change over time. Moving forward, more precise traffic data (e.g., collection in 1-minute intervals as opposed to 5-minute intervals) would provide greater utility with respect to the specific impacts of traffic volume and speed. Other relevant factors, such as weather and road surface condition, could also be integrated with the existing database.

Contacts

For more information:

Peter T. Savolainen
Principal Investigator
Wayne State University
5050 Anthony Wayne Drive, 0504.01 Engineering
Development Center, Detroit, MI 48202
313-577-9950
Fax 313-577-8126
savolainen@wayne.edu
www.cee.eng.wayne.edu

NEXTRANS Center
Purdue University - Discovery Park
2700 Kent B-100
West Lafayette, IN 47906

nextrans@purdue.edu
(765) 496-9729
(765) 807-3123 Fax

www.purdue.edu/dp/nextrans

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CHAPTER 1. INTRODUCTION

1.1 Background and motivation

Traffic incidents are generally described as any planned or unplanned event affecting traffic flow on a roadway (Sethi et al., 1994). These events result in the reduction of traffic flow, thus affecting the roadway capacity either directly by lane closure or indirectly by motorists slowing down to view the incident (Giuliano, 1988). Incidents include traffic crashes, vehicle breakdowns, the presence of debris on the road, and other events that cause a temporary reduction of roadway capacity (Hellinga et al., 2004). Incidents are of major concern as they disrupt the level of service provided by traffic facilities, diminish capacity, and create risks for those drivers directly involved (TRB, 1994). The congestion due to freeway incidents such as crashes, disabled vehicles, and weather events has been found to account for the majority of all congestion on metropolitan freeways in the United States (Giuliano, 1988; Lindley, 1987). In most urban areas, incident-related delay accounts for 50 to 60 percent of total congestion delay while in smaller urban areas, it can account for an even larger proportion (Farradyne, 2000). Beyond contributing to excessive delays, incidents can result in a significant safety hazards to uninformed motorists (Carvell et al., 1997), as well as to personnel responding to incidents (Neudorff et al., 2003). The risk of secondary crashes is also a critical problem. Incidents also have effects on the environment through increased fuel consumption and reductions in air quality. Other long-term effects of incidents include increased costs of commodities, services, and vehicle maintenance, as well as reduced productivity and negative impressions of the public agencies responsible for incident management (Wang et al., 2005b).

In response to the growing and adverse impacts of incidents, many communities have initiated incident management programs. These programs are aimed at detecting and responding to incidents in order to restore a freeway to full capacity by clearing the incident scene as soon as possible (Khattak and Rouphail, 2004). Incident management can be broadly described as a coordinated and well planned approach for restoring traffic to its normal operations as quickly as possible after an incident has occurred (Carvell et al., 1997). Such programs play an important role in the operation of the transportation system and require collaboration and efficient communication among various agencies, including fire and rescue, police, towing and recovery, transportation engineers, and freeway service patrol (Dougald and Demetsky, 2008). Incident management programs generally involve an organized use of human and mechanical processes for spotting and confirming the incident, judging the magnitude and identifying the requirement to restore the normal operation, as well as supplying a suitable response in the form of control, information, and aid (Carvell et al., 1997). Effective incident management programs can reduce the duration and impacts of incidents, consequently improving the safety for roadway users, incident victims, and responders.

The Detroit metropolitan area is home to one of the first freeway incident management programs in the United States, established by the Michigan Department of Transportation (MDOT). During the 1980s, MDOT implemented a program to reduce congestion during rush hours, offer immediate management, and provide traffic information to motorists. This system included surveillance cameras, dynamic message signs (DMS), motorists aid telephones, and ramp metering (Robinson and Nowak, 1993). Presently, MDOT operates the Freeway Courtesy Patrol (FCP) program as part of its larger freeway incident management program from the Michigan Intelligent Transportation Systems (MITS) Center in downtown Detroit. The FCP program has become an increasingly crucial component of the incident management program. Such FCP programs are widely used to help mitigate the effects of nonrecurring congestion (Dougald and Demetsky, 2008). FCP programs are normally active in high traffic areas, especially freeways, and are responsible for clearing debris and disabled vehicles from roadways, as well as assisting police with traffic control in the event of a crash (Dougald and Demetsky, 2008). Several State Departments of Transportation have carried out return-on-investment evaluations of their FCP programs and found the benefit-to-cost ratios (B/C) ranging up to 36 to 1 (Dougald and Demetsky, 2008).

The MITS Center, serves as the hub of ITS applications at MDOT where personnel administer a traffic surveillance system that covers 200 freeway miles. The center is able to monitor freeway performance through a series of in-pavement and roadside traffic detectors, as well as closed-circuit cameras. The cameras are used to identify incidents in combination with a hotline by which motorists can phone in incidents and other issues that they encounter on the road. When incidents are identified, FCP vans are dispatched to respond to the incident and provide assistance to affected motorists in a timely manner such that the freeway network can maintain operations at or near its capacity. Established in 1994, the MDOT FCP provides service to the motorists in Southeastern Michigan region by helping out stranded motorists, keeping freeways clear of vehicle breakdowns and traffic crashes, reducing travel time, and improving motorists' safety. The following is a list of the general services provided by the MDOT FCP to motorists (SEMCOG, 2009):

- Provides gas and other fluids to the disabled vehicles;
- Removes abandoned vehicles and debris from roadways;
- Fixes flat tires;
- Supplies minor mechanical assistance;
- Secure the area around your vehicle;
- Provides cell phone assistance;
- Provides up to five miles of towing at no charge;
- Transports stranded motorists;
- Provides directions.

In addition to reacting to dispatch calls, FCP vans roam the freeway network during the day and are thus able to respond to remote incidents in a more timely manner. Figure 1.1 illustrates the FCP coverage area within the Southeast Michigan freeway network. The locations of dynamic message signs (DMSs) for dissemination of messages/information to the motorists and close-circuit TV cameras (CCTV) to detect incidents are also illustrated in Figure 1.1.

Figure 1.1. Freeway Courtesy Patrol Coverage Area (MDOT, 2010a)

It is estimated that the FCP saved commuters 11.5 million hours of delay in 2008, in addition to reducing 2,094 kilograms per day of volatile organic compounds (VOC), 999 kilograms per day of nitrogen oxides (NOx) and 15,411 kilograms per day of carbon monoxide (CO) pollutants. The Southeastern Michigan Council of Governments (SEMCOG) estimates that for each dollar spending on FCP operation, a profit of $15.20

is realized. From 1994 to 2008, the FCP assisted 230,149 stranded motorists, made 108,440 unoccupied vehicle stops, and stopped to clear debris 12,460 times on southeastern Michigan freeways (SEMCOG, 2009).

Incident response time and clearance time are two critical components of the overall incident duration, which is a primary concern to motorists and transportation agencies. Incident duration is generally defined as the time elapsed between the occurrence of an incident and the time at which roadway is restored to its capacity (Garib et al., 1997; Nam and Mannering, 2000; Smith and Smith, 2001; Chung, 2010). The Highway Capacity Manual (TRB, 1994) divides a traffic incident into four distinct phases as shown in Figure 1.2:

- Incident Detection – the time between incident occurrence and its identification;
- Incident Response – the time between incident detection and arrival of the first responder on the scene;
- Incident Clearance – the time required for the incident response team to clear the incident scene; and
- Incident Recovery – the time between incident clearance and the recovery of the facility to its normal operating capacity.

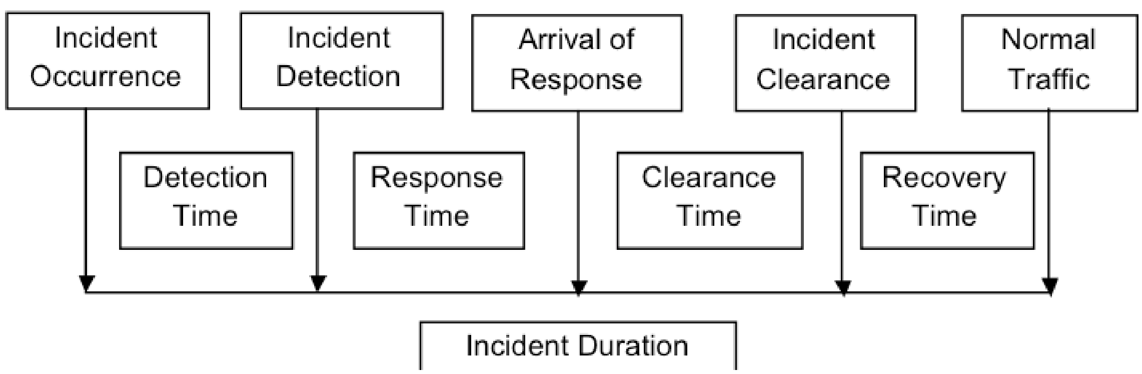


Figure 1.2. Components of a Typical Incident Duration (Nam and Mannering, 2000)

Incident durations can be significantly reduced through effective incident management. Incident clearance times are critical as they can be directly affected by a road agency. The incident clearance stage, which constitutes the safe and timely removal of stalled vehicles, wreckage, spilled materials and debris from the roadway or shoulders and reinstates the roadway to its full capacity is usually the most time consuming portion of the incident management process (Pearce, 2000). Quick clearance practices ensure the safety of responders and motorists involved in the incident by minimizing their exposure to the adjacent passing traffic (NCHRP, 2003). This necessitates the reduction of incident clearance to improve incident management operation. It has been found that the incident clearance process takes at least twice the duration of other steps in incident management process (Pearce, 2000).

1.2 Problem statement and research objectives

The MITS Center maintains a series of databases that detail freeway operations, as well as the activities of the FCP. However, these databases are independent of one another and no research has examined the relationships between freeway operations and the services provided by the MITS Center.

During the initial phase of research, a software interface was developed to link traffic flow and incident data. Using this interface, the purpose of this research is to utilize these data to examine incidents and identify factors affecting the clearance time of incidents on major freeways in the Detroit metro area.

1.3 Organization of the research

The report is organized into five chapters. Having outlined the importance of this study and the research objectives, the remainder of the study is organized as follows. Chapter 2 provides a state-of-the-art literature review of previous research in the area of freeway safety and operations. The research methodology is presented in Chapter 3. Chapter 4 presents details of the study area and the data utilized as a part of this study. Chapter 5 presents the study results, along with an accompanying discussion, as well as ultimate conclusions and directions for future research.

CHAPTER 2. STATE-OF-THE-ART LITERATURE REVIEW

Freeway incident management programs aim to minimize user delay by quickly reinstating the capacity of freeways (Konduri et al., 2003). To do so requires a systematic understanding of incident patterns, in order to restore roadways to full capacity (Konduri et al., 2003; Jones et al., 1991). Consequently, the collection and examination of incident-related data is of critical importance to freeway incident management systems. Such analyses are helpful in the selection of program strategies, and allocation of personnel in case of incident occurrence (Konduri et al., 2003; Jones et al., 1991).

Various methodological approaches have been used to analyze incident duration. These range from basic statistical methods, such as ANOVA or linear regression (Giuliano, 1988), to more rigorous techniques including multiple linear regression (Valenti et al., 2010), time sequential models (Khattak et al., 1995), non-parametric regression techniques (Nam and Mannering, 2000), and neural networks, as well as other decision tree methods (Valenti et al.,2010; Sethi et al., 1994; Ozbay and Noyan, 2006; Knibbe et al., 2006). A particularly attractive alternative for the analysis of such data are the family of hazard-based duration models, which allow for the examination of how various factors impact incident duration over time. Hazard models can be used to study how such factors affect the conditional likelihood of an incident ending at time t given that it has lasted until time t (Hensher and Mannering, 1994; Washington et al., 2010; Collet, 2003). Prior research has identified several factors to significantly affect incident duration. These include incident characteristics, environmental conditions, temporal factors, roadway geometry, traffic flow conditions, and freeway courtesy service characteristic.

In an early study, Golob et al. (1987) analyzed over 9,000 crashes involving trucks in the greater Los Angeles area. This research showed that clearance times were best characterized by a log-normal distribution. Giuliano (1988) expanded upon the study by Golob et al. (1987) and utilized a similar methodology in an analysis of 876 incidents in Los Angeles. Results showed that the factors affecting incident duration included incident type, time of day, day of week, accident type, truck involvement, and whether the incident required a lane closure.

Jones et al. (1991) assessed incident duration resulting from crashes and evaluated accident management strategies in the Seattle metropolitan area. Their results showed that duration was better characterized by a log-logistic distribution instead of log-normal. The time of year, time of day, lighting conditions, and characteristics related to the driver, vehicle, and type of crash were all found to impact duration. Interestingly, drunk drivers were found to be associated with shorter clearance times due to the higher urgency of law enforcement in response to alcohol-related crashes.

Skabardonis et al. (1999) carried out a field experiment on I-880 freeway in Los Angeles to determine factors affecting incident frequency and duration. After the implementation of a Freeway Service Patrol program, the average response time was reduced from 29 minutes to 18 minutes.

Stathopoulos and Karlaftis (2002) developed hazard-based duration models using data collected on a major road in the City of Athens, Greece to examine congestion resulting from an incident. This study showed that the log-logistic distribution best described the congestion duration in comparison to Weibull and Exponential distributions. It was found that congestion was most likely to diminish at 6 minutes and less likely to diminish when it persisted to more than 12 minutes.

Nam and Mannering (2000) developed hazard duration models for 700 incidents from Washington State. They developed separate models for the detection/reporting duration, the response duration, and the clearance duration. Incidents during the afternoon peak period, nighttime hours, and weekends were found to be associated with longer response times. For the incident detection and response models, a Weibull distribution with gamma heterogeneity provided the best fit when compared to all other parametric models. The log-logistic distribution provided the best fit for the clearance time duration model. Longer clearance times were observed during commuting and nighttime hours, as well as when fatalities or lane closures were involved.

Chung (2010) used the log-logistic accelerated failure time metric model to develop an accident duration prediction model for the Korean Freeway System. Duration was found to increase with the number of injuries and involved vehicles, as well as when fatalities were involved.

Alkaabi et al. (2011) found the Weibull accelerate failure time metric model (without gamma heterogeneity) to be the best-fit distribution for accident clearance data drawn from the City of Abu Dhabi, UAE. Longer clearance times were observed for crashes that occurred during off-peak hours, during the months of January and March, under severe weather conditions, and at locations with more severe injuries.

While several previous studies have examined incident duration, the MITS Center provides a robust dataset that allows for a more thorough investigation of the effects of incident-specific factors, as well as traffic flow and roadway geometry. This research builds off of previous work and involves the development of a series of duration models to assess those factors affecting the time required to clear freeway incidents. Various model formulations are compared and the transferability of model results across freeway segments is assessed.

CHAPTER 3. METHODOLOGY

In transportation research, hazard-based duration models have been used to analyze traffic crashes (Jovanis and Chang, 1989; Chang and Jovanis, 1990; Mannering, 1993), trip-making decisions (Mannering, 1993; Hamed and Mannering, 1993; Bhat, 1996a; Bhat, 1996b; Bhat et al., 2004), and vehicle ownership (Mannering and Winston, 1991; Gilbert, 1992; De Jong, 1996; Yamamoto and Kitamura, 2000), as well as incident duration (Nam and Mannering, 2000; Chung, 2010; Jones et al., 1991; Stathopoulos and Karlaftis, 2002; Alkaabi et al., 2011). Hazard models are well suited for analyzing duration data that include well-defined start and end points (Collett, 2003), such as the incident clearance data analyzed as a part of this study. Within the context of this study, each incident is defined by an explicit origin (the time the FCP vehicle arrives on the scene), as well as an explicit end point (the time the FCP leaves the scene after clearing the incident).

As a part of this study, hazard models were developed to examine the likelihood that an incident will be cleared during the time period $(t + \Delta t)$ given that it has already lasted until time t. This clearance duration is impacted by several factors of interest, including the type of incident, time-of-day, and others, the effects of which can be captured by the hazard model. This relationship is modeled as follows.

First, a cumulative distribution function is defined of the following form:

$$F(t) = \Pr(T < t).$$

This equation specifies the probability that a random variable, *T*, is less than some specified value, *t*. In this case, it is the probability that an incident has a clearance duration less than *t*. This function leads to a related survivor function of the form:

$$S(t) = \Pr(T \geq t) = 1 - F(t),$$

which gives the probability that an incident has a clearance duration greater than or equal to *t*. The corresponding density *f(t)* and hazard function *h(t)* are as follows:

$$f(t) = dF(t)/dt$$

$$h(t) = f(t)/S(t).$$

The hazard function provides the instantaneous probability that an incident will be cleared during the infinitesimally small time interval between *t* and *(t+Δt)*. The slope of this function captures dependence of the probability of a duration ending based upon the current duration, termed as duration dependence. When the slope of the hazard function, *dh(t)/dt*, is greater than 0, the function is termed to have positive duration dependence, indicating the longer the duration of the incident is, the more likely the incident is to be cleared soon. The converse case is termed negative duration dependence. *dh(t)/dt*=0 signifies that the probability of incident clearance is constant and independent of time.

Hazard-based duration models can also explain the effect of covariates on these probabilities (Washington et al., 2010).

The models developed herein are referred to as proportional hazards models. They operate on the assumption that covariates act multiplicatively on some baseline hazard function. The hazard function with covariates is of the form:

$$h(t, \beta, X, h_0) = h_0(t)y(\beta, X),$$

where t is time, X is a vector of explanatory variables, β is a vector of estimable parameters, $h_0(t)$ is the baseline hazard model (i.e., the hazard at $\beta X = 0$), and $y(\beta X)$ is a scaling factor of the form $\exp(\beta X)$.

Several distribution functions are candidates for such models, including the Weibull, log-normal and log-logistic distributions. Earlier studies found that these distributions exhibit very diverse behaviors (Nam and Mannering, 2000; Chung, 2010; Jones et al., 1991; Stathopoulos and Karlaftis, 2002; Alkaabi et al., 2011) and the choice of an appropriate functional form for the duration distribution is critical as it not only defines the shape of the underlying hazard, but also affects the efficiency and potential bias of the estimated parameters (Washington et al., 2010).

In the formulation of proportional hazard models, the survival function is assumed to be homogeneous across observations. However, problem arises when some of the unobserved factors affect the durations and cause heterogeneity. This unobserved heterogeneity can result in major specification error leading to erroneous inferences on the shape of the hazard function and inconsistent parameter estimates. In fully parametric models, a new parameter can be introduced to capture unobserved effects across the data and work with the resulting conditional survival function. For the purposes of this research, one such model (assuming a Weibull distribution with gamma heterogeneity) was developed as a part of this study and compared to three other model specifications (assuming a Weibull distribution without heterogeneity, a log-normal distribution, and a log-logistic distribution). These models were compared using a likelihood ratio test to determine which provided a best fit for the analysis dataset.

3.1 Assessing Spatial Transferability of Models

Likelihood ratio tests were also utilized to examine the spatial transferability of the models to determine how the impacts of specific factors varied among the four freeways analyzed as a part of this study.

Incident clearance durations may vary across freeway segments due to variation in factors such as the distance from the nearest traffic management centers from where FCP operators are dispatched, the allocation of roaming FCP operators among freeways, geometrical characteristics (e.g., presence of horizontal and vertical curves, number of lanes, shoulder width, etc.), and other factors.

To examine the transferability of parameters between two or more freeways, the likelihood ratio test is conducted (Washington et al., 2003):

$$\chi^2 = -2[LL(\beta_T) - LL(\beta_a) - LL(\beta_b)],$$

where $LL(\beta_T)$ is the log-likelihood value at convergence of the model using the total dataset from both freeways a and b, $LL(\beta_a)$ is the log-likelihood at convergence of the model using data from only freeway a data and $LL(\beta_b)$ is the log-likelihood value at convergence of the model using data for only freeway b data (these results can be generalized to more than two freeways). The same variables are included in each of the three models. The resulting likelihood ratio test statistic follows the chi-square distribution (X^2) and has degrees of freedom equal to the difference in the total number of estimated parameters among the freeway-specific models and the number of estimated parameters in the overall model that includes data for all freeways. The null hypothesis is that the parameter effects are equal across each freeway. For the purposes of this study, a likelihood ratio test is conducted to compare whether a single joint model provides substantively different results than four freeway-specific duration models.

CHAPTER 4. DATA

The primary objective of this research is to assess the data that is being collected and maintained by the Michigan Department of Transportation (MDOT) Michigan Intelligent Transportation Systems (MITS) Center and to use these data to examine incident clearance operations on the southeastern Michigan freeway network. A software interface was developed previously in order to integrate two databases for subsequent data analysis activities (Savolainen and Ghosh, 2010). To analyze the freeway operations in Detroit metro area, data are obtained from two primary sources: traffic flow data from roadside sensors collected by Traffic.com and Freeway Courtesy Patrol (FCP) operational data maintained by the MITS Center.

4.1 Traffic.com Traffic Flow Data

Traffic.com provides information on traffic conditions for a specific metropolitan area by utilizing a map of the Detroit metro area, including traffic flow data, as well as a summary of incidents, events, and roadwork. The Traffic.com sensor manager feature provides MDOT with detailed data related to traffic on those corridors that are covered by microwave side-fire detectors. Table 4.1 provides a list of important variables along with a brief description of each. Sensor data are available in 5 minute intervals for each sensor. This results in up to 288 observations for a specific day for each sensor. Traffic.com maintains a total of 110 sensors along four local major freeways (Interstate 75, Interstate 94, Interstate 275 and Interstate 696) in the Detroit metro area. A map showing the locations of these sensors is shown in Figure 4.1. For this study, traffic flow data from a sample of the 110 active sensors were extracted and analyzed. Each of these sensors provides data related to time, number of lanes, average vehicular speed, total number of vehicles along with vehicle classes (Class I, Class II, Class III and Class IV), and detection zone occupancy information for each direction of travel. Mile markers along each freeway for these 110 sensors are also available from Traffic.com.

Table 4.1 - List of Variables Included In the Sensor Database (Traffic.Com, 2010)

Name	**Description**
Time	Timestamp
Sensor	Unique sensor ID number (for all lanes)
Device	Sensor device ID (per lane, or zero for all lanes combined)
Direction	Direction of vehicular travel
Lane Position	Location of incident within lane
Lane Type	Type of lane: Thru (mainline), on-ramp, off-ramp, etc.
Speed	Average speed in MPH
Volume	Total count of all vehicles that were measured by vehicle class
Occupancy	The percentage of time that a roadway detection zone was “occupied”

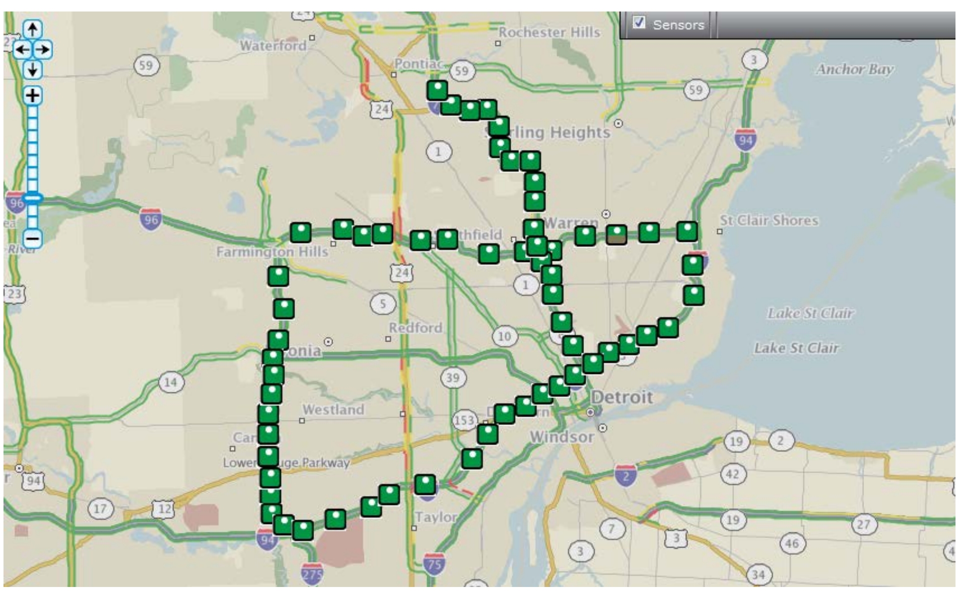


Figure 4.1. Location of Traffic.com Maintained Sensors (Traffic.com, 2010)

4.2 Freeway Courtesy Patrol (FCP) Data

Incident-related data for 2009 are obtained from a database maintained by the MDOT MITS center for its FCP program. During each FCP call, data are recorded related to each incident. These data include information related to each vehicle (vehicle classification, state of vehicle registration, year, model, color as well as manufacturer of vehicle), incident location (county name, name and type of freeway, direction, nearest cross street, mile marker on freeways), incident type (abandoned vehicle, flat tire, out of gas, mechanical trouble, debris, crash, other, etc), type of service provided by the response team and total time taken by the operator to reach the incident scene and to clear the incident. Table 4.2 provides a list of variables present in the FCP database along with their description.

For this study, traffic flow information is obtained from side-fire microwave detectors maintained by Traffic.com for different freeways in metro Detroit. Incidents were examined for the year 2009 along four local major freeways: Interstate 75 (I-75), Interstate 94 (I-95), Interstate 275 (I-275), and Interstate 696 (I-696). Traffic flow data from 110 active sensors along these freeways were extracted and analyzed. The data provided by each sensor includes speed, volumes by vehicle class, and sensor occupancy information for each direction of travel on a lane-by-lane basis. The data are aggregated into 5-minute intervals. Incident-related data for 2009 are obtained from MDOT's MITS center. These data include information on each incident-involved vehicle, the incident location, type of incident, details of the services provided by the FCP, the time required for the FCP operator to reach the incident scene (for dispatched vehicles), and the time required by the FCP operator to clear the incident scene.

Table 4.2 - List of Variables Included In the FCP Database

Name	**Description**
Day of Week	Day that the Call occurred
ccDateDD	Date the Call occurred
ccDispatched	The time FCP operator was dispatched
ccArrived	The time FCP operator arrived on the scene
ccCleared	The time FCP operator left the scene
typVehicleType	Type of vehicle
ccVehicleYear	Model year of the vehicle
vmMake	Manufacturer of the vehicle
vmmModel	Model of the vehicle
ccOccupants	Number of persons in the vehicle
fwdDirection	The route direction of the freeway
ccMileMarker	Mile marker of the Call location
ccLaneBlocked	Whether any lanes/shoulders were blocked
ccTroubleType	Problem which prompted Call
ccServiceType	Service performed by the FCP operator
ResponseTime	Time required for FCP operator to arrive on-scene if dispatched
ClearTime	Time required for FCP operator to clear the incident
fcp_Longt	Longitude of the Call location
fcp_Lati	Latitude of the Call location

In order to assess the impact of incidents on freeway operations, the incident data was linked to traffic flow through a software program that was developed as a part of this project (Savolainen and Ghosh, 2010). The four freeways were found to experience a total of 32,574 incidents after the removal of cases with incomplete or missing information. The average clearance time for these incidents is observed as 9.81 minutes, which is lower than previous studies that have shown average clearance times of 13 to 20 minutes in Los Angeles (Jovanis and Chang, 1989; Skabardonis et al., 1997), 18 minutes in Abu-Dhabi (Alkaabi, 2011), 78 minutes in Ohio (Lee and Fazio, 2005), and 136 minutes in Seattle (Jones et al., 1991). The minimum and maximum incident clearance times included in the study sample were 1 minute and 182 minutes, respectively. The lower clearance times exhibited by the incidents in this study are likely due to the fact that prior studies tended to focus on major incidents with significant impacts on traffic flow (Nam and Mannering, 2000) or crashes (Jones et al., 1991; Lee and Fazio, 2005). Conversely, this study considered all types of incidents on freeways attended by FCP operators.

Table 4.3 provides summary information for the incidents analyzed in this study. Incidents were slightly less frequent during the weekends when both traffic volumes and the number of FCP vehicles in operation were lower. Incident frequency also tended to mirror traffic volumes, increasing to a peak during the summer before declining again into the winter. Incidents were most frequent on I-75 and I-94, the freeways that are subject to the highest volume of traffic among those covered by the FCP.

The vast majority of incidents (98.9 percent) involved only one vehicle and over 88 percent of the incidents occurred within the shoulder, with 10 percent impacting a single lane, and the remainder impacting multiple travel lanes. About 91 percent of incidents occurred during the morning (6 AM to 2 PM) and afternoon (2 PM to 10 PM) shifts. Incidents generally tended to decrease during the winter months (with a low in February) and increase during the summer months (peaking in August). The majority of incidents were found to occur on I-75 and I-94, the two freeways that serve the highest volume of traffic on the Detroit freeway network.

Table 4.3 - Summary Statistics for Freeway Courtesy Patrol Incidents

Variable	Frequency (percentage)	Variable	Frequency (percentage)
Day of Week		*Number of Vehicles Involved*	
Weekend	27,082 (83.1%)	One Vehicle	32,208 (98.9%)
Weekday	5,492 (16.9%)	Multiple vehicles	366 (1.1%)
Month		*Service Type*	
January	2,214 (6.8%)	Abandoned vehicle	9,862 (30.3%)
February	2,158 (6.6%)	Flat tire	4,313 (13.2%)
March	2,404 (7.4%)	Out of gas	2,757 (8.5%)
April	2,941 (9.0%)	Mechanical problems	2,038 (6.3%)
May	2,721 (8.4%)	Clearing debris	1,678 (5.1%)
June	2,710 (8.3%)	Directing traffic	740 (2.3%)
July	2,832 (8.7%)	Towing	2,052 (6.3%)
August	3,295 (10.1%)	Standby for EMS/Towing	675 (2.1%)
September	2,963 (9.1%)	Transporting motorist	278 (0.9%)
October	3,042 (9.3%)	Providing cell phone	126 (0.4%)
November	2,720 (8.4%)	Gone on arrival	222 (0.7%)
December	2,574 (7.9%)	Providing directions	404 (1.2%)
		Service declined by driver	3,202 (9.8%)
Freeway		Other services	859 (2.6%)
I-75	10,760 (33.0%)	Multiple services required	3,368 (10.3%)
I-275	3,828 (11.7%)		
I-94	12,981 (39.9%)	*FCP Operator Dispatch Time*	
I-696	5,005 (15.4%)	First shift (10 pm - 6 am)	305 (8.5%)
		Second shift (6 am - 2 pm)	1,453 (40.3%)
Direction of Travel		Third shift (2 pm -10 pm)	1,845 (51.2%)
Northbound	7,520 (23.1%)		
Southbound	7,068 (21.7%)	*FCP Operator Arrival Time*	
Eastbound	8,803 (27.0%)	First shift (10 pm - 6 am)	2,875 (8.8%)
Westbound	9,183 (28.2%)	Second shift (6 am - 2 pm)	15,469 (47.5%)
		Third shift (2 pm -10 pm)	14,230 (43.7%)
Area of Roadway Affected			
Shoulder only	28,900 (88.7%)	*Incident Clearance Time*	
Exactly one travel lane	3,258 (10.0%)	First shift (10 pm - 6 am)	2,875 (8.8%)
More than one travel lane	416 (1.3%)	Second shift (6 am - 2 pm)	15,301 (47.0%)
		Third shift (2 pm -10 pm)	14,397 (44.2%)

The most frequently provided FCP services were in response to abandoned vehicles (30 percent), followed by flat tires (13 percent), incidents requiring multiple services (10 percent), vehicles running out of gas (8 percent), and mechanical problems or requiring a tow (6 percent). In approximately 10 percent of the cases, the driver of the incident-involved vehicle declined any assistance from the FCP responder. Each of the other remaining service types constituted less than 6 percent of the total sample.

For analysis purposes, each of these four freeways is divided into finite-length sections of one-mile length to examine how site-specific variables (e.g., number of lanes, horizontal curves, entrance, exit ramps, presence of horizontal curves, maximum and minimum radii of horizontal curves) influence clearance times and how these impacts vary across freeway segments. Each direction of travel is considered as a unique segment. Consequently, the total freeway network is disaggregated into 422 one-mile segments. The geometric features (e.g., number of lanes, horizontal curvature, etc.) and traffic information (e.g., 85th and 15th percentile speed, peak hour volume, etc.) are collected for each of these sections and summary statistics are presented in Table 3.4.

Table 4.4 - Summary Statistics for Freeway Sections in Analysis Sample

Variable	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Incident frequency (per month)	0	43	6.4	6.3
85^{th} percentile speed (mph)	59	76	68.5	3.3
15^{th} percentile speed (mph)	48	68	58.7	3.8
Peak hour volume (vph)	2,892	6,720	4,494.2	910.8
Number of lanes	2	4	3.1	0.4
Number of horizontal curves	0	3	0.8	0.8
Minimum radius of the horizontal curve (ft)	N/A	4,365	1,328.1	1,287.4
Number of entrance ramps	0	3	0.9	0.8
Number of exit ramps	0	3	0.8	0.7

Note: Data represents 422 freeway sections of one-mile length on I-75, I-275, I-94, and I-696

In 2009, the maximum number of incidents experienced on any freeway segment was 43, whereas there were 46 segments with no history of incidents during the one-year analysis period. The 85th percentile speeds ranged from 59 to 76 mph and the 15th percentile speeds ranged from 48 to 68 mph. Peak hour volumes varied between 2,892 and 6,720 vehicles per hour. The minimum curve radius found within each segment ranged from 1,328 feet to 4,365 feet and the number of exit and entrance ramps ranged from zero to three.

CHAPTER 5. RESULTS AND DISCUSSIONS

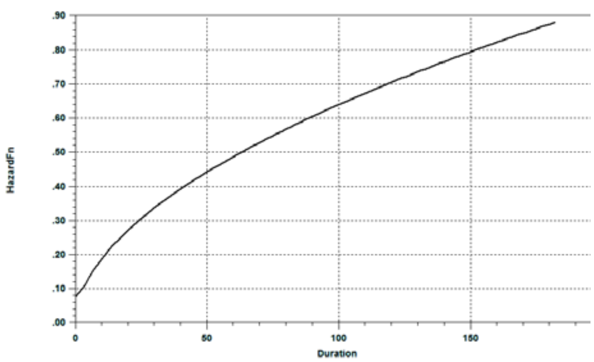
5.1 Incident Duration Model Results

Four hazard-based duration models were developed to examine the time required by FCP operators to clear incidents along the segments of the four local freeways. Each duration model assumed a different underlying distribution for the hazard function, which included the following:

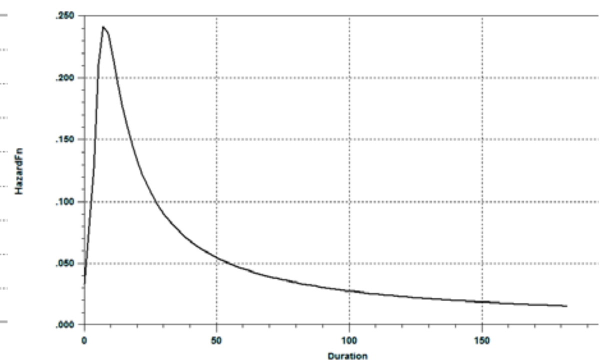
- Weibull distribution without heterogeneity
- Weibull distribution with heterogeneity
- Log-normal distribution
- Log-logistic distributions

Figure 5.1 presents plots of each of these four hazard functions against incident duration. It is obvious from these diagrams that three of the four distributions are quite similar to one another, with the exception being the Weibull distribution without heterogeneity. In the case of the latter, the hazard function increases continually, which means that the longer an incident has lasted without being cleared, the more likely it is to be cleared (without exception). In the case of the other three distributions, the hazard function increases until reaching an apex (with the probability of clearance increasing over this period), followed by a decline (as the probability of clearance decreases). This reflects the fact that certain types of incidents tend to be cleared very quickly while other, more severe incidents tend to take a much longer time to clear (leading to the long tail that approaches zero).

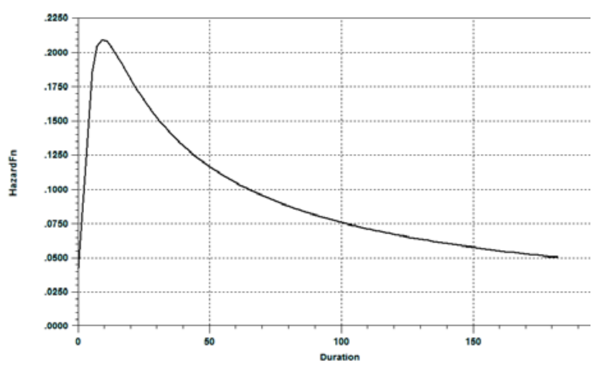
Table 5.1 presents the results for these four models, including the parameter estimates, as well as the t-statistics for each variable. Likelihood ratio statistics are also provided, which show the log-logistic model to provide the best fit (highest likelihood ratio statistic) for the dataset, followed closely by the Weibull model with gamma heterogeneity and the log-normal model. This is consistent previous research by Nam and Mannering (2000) and Chung (2010). The Weibull model without heterogeneity provides the poorest fit among the four alternative models. However, regardless of the underlying distribution, the parameter estimates are quite consistent across the four models. All variables were found to be significant at a 95 percent confidence level. A discussion of the significant variables affecting incident clearance follows. Elasticity values of the factors are presented in Table 5.2 and discussed thereafter to evaluate the impacts of the parameters. The discussion is based upon the results of the log-logistic hazard model.



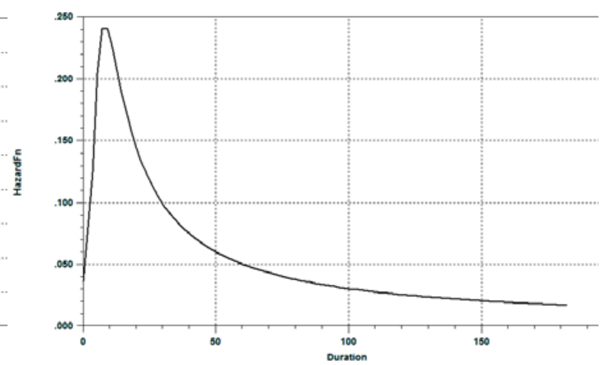
Weibull Distribution (No Heterogeneity Effect)



Weibull Distribution with Gamma Heterogeneity



Log-normal Distribution



Log-logistic Distribution

Figure 5.1. Hazard Functions for Each Underlying Distribution

Table 5.1 - Estimation Results for Incident Clearance Duration Models

Variable	Weibull	Weibull with heterogeneity	Log-normal	Log-logistic
Constant	1.234(34.082)	0.969(15.917)	1.038(17.755)	0.973(16.332)
Weekday first shift (10 pm-6 am)	-0.121(-13.095)	-0.120(-8.243)	-0.117(-7.708)	-0.123(-8.403)
Weekend	-0.180(-31.267)	-0.234(-26.026)	-0.211(-22.358)	-0.235(-26.059)
Winter	0.035(7.018)	0.053(7.974)	0.053(7.513)	0.053(7.868)
Interstate 75 (I-75)	0.168(33.585)	0.103(14.190)	0.113(14.627)	0.109(14.958)
Interstate 275 (I-275)	0.007(0.929)	-0.030(-2.660)	-0.015(-1.220)	-0.027(-2.457)
Tangent section	-0.026(-5.445)	-0.030(-4.433)	-0.029(-4.026)	-0.030(-4.330)
No exit ramp	0.027(4.499)	0.027(3.117)	0.027(2.964)	0.027(3.045)
One vehicle	-0.220(-7.777)	-0.493(-16.546)	-0.436(-14.467)	-0.472(-15.662)
Inside shoulder	0.073(7.583)	0.049(4.101)	0.056(4.585)	0.053(4.423)
Only shoulder	-0.457(-26.522)	-0.372(-13.710)	-0.382(-15.067)	-0.377(-13.862)
Single lane	-0.311(-19.313)	-0.322(-11.835)	-0.327(-12.787)	-0.321(-11.774)
Service abandoned vehicles	0.924(71.931)	1.197(25.899)	1.092(25.084)	1.194(27.037)
Service tire	2.088(138.070)	2.380(50.838)	2.279(51.200)	2.376(53.072)
Service gas	1.404(100.795)	1.674(35.232)	1.575(34.690)	1.668(36.654)
Service mechanical	1.918(120.464)	2.062(43.564)	1.980(44.124)	2.071(45.696)
Service debris	0.781(45.091)	1.004(20.695)	0.908(19.674)	1.005(21.566)
Service traffic	2.414(127.755)	2.317(47.073)	2.258(48.928)	2.350(49.699)
Service FCP towing	2.235(144.144)	2.152(45.334)	2.096(47.125)	2.186(48.139)
Service non-FCP towing	1.894(101.508)	1.684(34.224)	1.664(36.295)	1.719(36.435)
Service stand-by	2.094(104.074)	1.968(39.800)	1.940(41.751)	1.999(42.117)
Service transportation	2.640(74.338)	2.825(49.643)	2.731(47.992)	2.831(51.092)
Service cell phone	1.065(32.994)	1.056(14.813)	1.028(15.407)	1.060(15.317)
Service direction	0.950(38.921)	1.166(21.481)	1.066(19.768)	1.169(22.168)
Service declined	1.057(79.566)	1.206(25.734)	1.112(25.120)	1.210(26.986)
Other services	1.415(87.212)	1.233(25.465)	1.147(25.550)	1.266(27.297)
Multiple services	2.560(176.075)	2.603(55.955)	2.508(57.456)	2.623(59.020)
7 mph Difference in 15^{th} & 85^{th}	0.040(7.360)	0.021(2.936)	0.024(3.184)	0.022(3.081)
85^{th} percentile speed ≤ 70 mph	0.042(6.532)	0.036(4.021)	0.034(3.572)	0.037(4.151)
σ (Distribution parameter)	0.650(393.436)	0.314(115.475)	0.613(321.243)	0.334(223.390)
θ (Heterogeneity)	-	1.178(51.014)	-	-
P (Scale parameter)	1.538	3.190	1.632	2.999
λ (Shift parameter)	0.113	0.159	0.153	0.154
Likelihood ratio statistic	23,000.400	24,177.400	22,569.940	24,614.740

Note: Parameter estimates are provided for each model formulation, followed by t-statistics in parentheses.

Table 6.2 - Variable Elasticities for Incident Clearance Duration Model

Variable	Weibull	Weibull with heterogeneity	Log-normal	Log-logistic
Weekday (10 pm -6 am)	-11.4%	-11.3%	-11.0%	-11.6%
Weekend	-16.5%	-20.9%	-19.0%	-20.9%
Winter	3.6%	5.4%	5.4%	5.4%
Interstate 75 (I-75)	18.3%	10.9%	12.0%	11.5%
Interstate 275 (I-275)	0.7%	-3.0%	-1.5%	-2.7%
Tangent section	-2.6%	-3.0%	-2.9%	-3.0%
No exit ramp	2.7%	2.7%	2.7%	2.7%
One vehicle	-19.8%	-38.9%	-35.3%	-37.6%
Inside shoulder	7.6%	5.0%	5.8%	5.4%
Only shoulder	-36.7%	-31.1%	-31.8%	-31.4%
Single lane	-26.7%	-27.5%	-27.9%	-27.5%
Service abandoned vehicles	151.9%	231.0%	198.0%	230.0%
Service tire	706.9%	980.5%	876.7%	976.2%
Service gas	307.2%	433.4%	383.1%	430.2%
Service mechanical	580.7%	686.2%	624.3%	693.3%
Service debris	118.4%	172.9%	147.9%	173.2%
Service traffic	1017.9%	914.5%	856.4%	948.6%
Service FCP towing	834.7%	760.2%	713.4%	790.0%
Service non-FCP towing	564.6%	438.7%	428.0%	457.9%
Service stand-by	711.7%	615.6%	595.9%	638.2%
Service transportation	1301.3%	1586.1%	1434.8%	1596.2%
Service cell phone	190.1%	187.5%	179.6%	188.6%
Service direction	158.6%	220.9%	190.4%	221.9%
Service declined	187.8%	234.0%	204.0%	235.4%
Other services	311.7%	243.2%	214.9%	254.7%
Multiple services	1193.6%	1250.4%	1128.0%	1277.7%
7 mph Difference in 15^{th} & 85^{th}	4.1%	2.1%	2.4%	2.2%
85^{th} percentile speed ≤ 70 mph	4.3%	3.7%	3.5%	3.8%

5.2 *Temporal Factors*

Clearance times were 11.6 percent shorter during the first shift (10 pm to 6 am) on weekdays. This finding is likely due to lower traffic volumes during this time period, which allow FCP operators to safely clear the incident in a more timely manner. This finding is in contrast to several previous studies that showed longer clearance times during nighttime hours due to the availability of fewer assigned response teams, as well as poor visibility (Nam and Mannering, 2000; Chung, 2000; Madanat and Feroze, 1997).

Clearance times were also found to be 21.0 percent lower during weekend days, another presumed byproduct of reduced traffic volumes. Incidents tended to take longer to clear during the winter, which may be due to the effects of inclement weather or snow buildup on the shoulders, each of which deter the clearance process.

5.3 *Location-Specific Factors*

Incidents on I-75 tended to have longer clearance times, another factor that is likely volume-related as I-75 is subject to the largest traffic volumes among the four freeways. Conversely, the lower traffic volumes on I-275 led to incidents clearing more quickly.

Incidents that occurred on freeway sections with no exit ramps tended to take longer to clear. Exit ramps provide an opportunity for motorists who were not involved in the incident to get off of the freeway and also provide a potential access point for first responders, as well.

Incidents occurring on tangent segments (with no horizontal curves) tended to have shorter clearance times. Such segments tended to exhibit higher operating speeds and less variability in speeds, which would allow these segments to more easily accommodate the capacity reductions created by incidents.

Traffic conditions also influenced clearance times as locations with lower mean speeds and higher variability in speeds tended to experience longer clearance times. At locations where the 85^{th} percentile speed was 70 mph or less, incidents took 3.7 percent more time to clear. At locations where the difference between the 15^{th} and 85^{th} percentile speeds was greater than 7 mph also experienced longer clearance times. This finding, consistent with other studies (Ullman and Ogden, 1996), is reflective of higher levels of congestion on such segments, which is likely to inhibit the incident clearance process.

5.4 Incident Characteristics

Incidents involving a single vehicle cleared 37.6 percent sooner than multi-vehicle incidents. While this finding differs from the results of a study in Houston, TX (Ullman and Ogden, 1996) that analyzed major freeway incidents, the latter study focused on incidents that blocked a lane for 45 minutes to an hour. The clearance times in this study were generally much shorter (average 8.18 minutes), so as additional vehicles are affected, clearance times would be expected to increase accordingly.

The location at which the incident occurred also had a major impact on clearance times. Clearance times were greatest when multiple lanes of traffic were affected. Incidents that occurred on the right shoulder cleared 31.4 percent sooner and incidents that impacted only one lane cleared 27.5 percent faster. Conversely, incidents occurring on the left (inside) shoulder were more likely to affect adjacent traffic, resulting in a 5.4 percent increase in clearance time.

Incidents that required the FCP operator to provide transportation to stranded motorists required the longest clearance times, followed by other incidents requiring multiple services from the FCP. These cases required clearance times that were 16 times and 12 times as long as incidents where the vehicle was gone on arrival, respectively. In the case of a vehicle being gone on arrival, the FCP vehicle scans the incident scene, fills out the report form, and leaves the scene. Incidents requiring towing also took longer to clear, as did cases where the incident-involved vehicle had a flat tire or mechanical problems. The incidents with the lowest clearance times were cases where the motorist only required directions or the use of a cell phone, as well as cases where the motorist refused service by the FCP operator.

5.5 *Assessment of Spatial Transferability*

To gain greater insight into the effects of the previously described factors, the spatial stability of the parameter estimates from the duration model was examined by developing separate models for each of the four individual freeways considered in this study. Table 5.3 provides parameter estimates for each of these four models. Similar to the joint model that combined data from all four freeways, a log-logistic hazard function was found to perform best for each freeway individually, as well.

It is evident from the model results that many of the variables tend to have similar effects across the four freeways. Parameter estimates were generally within 10 percent of one another among the four freeway-specific models. In some cases, parameters were found to exhibit the opposite signs for a specific freeway (e.g., variability in 15th and 85th percentile speeds), though these effects were not found to be statistically significant.

While the model results were relatively consistent, the magnitude of the variable impacts varied across freeways. A likelihood ratio test showed that the four freeway-specific models outperformed the single joint model at a 99 percent confidence level as shown in Table 5.4. The source of this instability in parameters may be due to varying traffic conditions and changes in geometrical features along each freeway, as well as differences in incident characteristics. Despite these differences, the results ultimately show that the results from the single model provide estimates that are generally transferable across freeways.

Table 7.3 - Estimation Results of Freeway-Specific Clearance Time Models

Variable	Interstate 75	Interstate 275	Interstate 94	Interstate 696
Constant	1.146(10.522)	0.831(4.408)	1.004(10.835)	0.735(5.583)
Weekday first shift (10 pm-6 am)	-0.213(-7.240)	-0.120(-2.815)	-0.045(-2.132)	-0.162(-4.677)
Weekend	-0.320(-19.447)	-0.264(-10.104)	-0.163(-11.884)	-0.238(-10.745)
Winter	0.030(2.371)	0.128(7.031)	0.070(6.676)	-0.007(-0.423)
One vehicle	-0.514(-9.495)	-0.272(-3.355)	-0.512(-9.514)	-0.330(-5.742)
Inside shoulder	0.065(2.868)	-0.025(-0.915)	0.086(4.542)	0.039(1.326)
Only shoulder	-0.475(-9.894)	-0.392(-4.217)	-0.335(-7.292)	-0.243(-4.330)
Single lane	-0.375(-7.836)	-0.362(-3.934)	-0.288(-6.270)	-0.217(-3.753)
Service abandoned vehicles	1.299(15.777)	1.059(7.160)	1.132(17.592)	1.222(12.165)
Service tire	2.397(28.663)	2.298(15.435)	2.377(36.394)	2.368(23.255)
Service gas	1.733(20.466)	1.618(10.705)	1.634(24.546)	1.645(15.781)
Service mechanical	2.104(24.813)	2.115(14.064)	2.029(30.801)	2.066(19.910)
Service debris	1.030(11.897)	0.842(5.513)	0.965(14.099)	1.171(10.874)
Service traffic	2.353(26.723)	2.348(14.724)	2.277(32.831)	2.510(23.418)
Service FCP towing	2.297(27.165)	2.110(13.968)	2.099(31.673)	2.190(21.000)
Service non-FCP towing	1.861(21.012)	1.724(11.293)	1.562(22.380)	1.796(16.789)
Service stand-by	2.207(24.355)	2.368(14.889)	1.917(27.975)	1.682(15.593)
Service transportation	2.963(28.870)	2.720(15.105)	2.750(33.733)	2.818(22.105)
Service cell phone	0.959(6.840)	2.268(8.256)	1.034(10.138)	1.117(7.636)
Service direction	1.288(12.647)	1.184(7.372)	1.084(14.168)	1.041(8.059)
Service declined	1.263(15.052)	1.137(7.605)	1.191(18.290)	1.187(11.610)
Other services	1.315(15.209)	1.500(9.734)	1.244(18.335)	1.034(9.735)
Multiple services	2.560(30.792)	2.737(18.405)	2.591(40.110)	2.767(27.380)
Difference between 85^{th} and 15^{th} percentile speed > 7mph	0.068(5.016)	0.052(2.571)	-0.014(-1.306)	-0.015(-0.703)
85^{th} percentile speed ≤ 70 mph	0.057(3.427)	-0.004(-0.215)	0.036(2.270)	0.059(2.116)
Tangent section	-0.024(-1.876)	-0.039(-1.933)	-0.034(-3.072)	0.000(0.015)
No exit ramp	0.062(3.558)	0.012(0.589)	0.057(3.113)	-0.028(-1.600)
σ (Distribution parameter)	0.355(123.655)	0.313(76.249)	0.322(142.780)	0.314(90.923)
P (Scale parameter)	2.813	3.191	3.109	3.186
λ (Shift parameter)	0.142	0.165	0.161	0.155
Number of parameters	28	28	28	28
Initial log-likelihood	-13,943.680	-4,961.093	-16,449.010	-6,424.096
Log likelihood at convergence	-10,400.770	-3,237.309	-11,348.900	-4,269.522
Number of observations	10,760	3,828	12,981	5,005

Note: Parameter estimates are provided for each model formulation, followed by t-statistics in parentheses.

Table 8.4 - Results of Spatial Transferability Test for Clearance Time Model

Models	**Log likelihood at convergence**
Clearance time model (Log-logistic distribution)	
Interstate 75	-10,400.770
Interstate 275	-3,237.309
Interstate 94	-11,348.900
Interstate 696	-4,269.522
Summation of all individual Freeway model	-29,256.501
Overall model	-29,577.990
X^2	321.489
Degrees of freedom	82
p-value	0.000

CHAPTER 6. CONCLUSIONS

This study involved survival analyses aimed at identifying those factors that impact the time required by Freeway Courtesy Patrol (FCP) personnel to clear an incident scene. The data analyzed included incident information collected by the FCP incident responder, traffic data provided by roadside traffic detectors, and geometric information for each study segment. Four model formulations were examined, each assuming a different underlying distribution for the hazard function. The results showed the log-logistic distribution to provide the best fit for the incident clearance data in comparison to other parametric models, though each of the models produced consistent parameter estimates.

Shorter clearance times were observed during weekends and the morning shift on weekdays when volumes were lower. Several other volume-related factors were also shown to have significant impacts, including the route on which the incident occurred, the 85^{th} percentile speed on the segment, and the variability in speeds as measured by the difference between the 15^{th} and 85^{th} percentile speeds.

Clearance times were longer during the winter months, when incidents impacted adjacent traffic or required the closure of travel lanes, on segments with horizontal curves, or where no exit ramps were available for motorists or FCP responders.

From an analytical standpoint, this study showed that hazard-based duration models provide an appropriate tool for assessing incident durations. The findings from these models can be used to more efficiently manage the incident clearance process. Additionally, these models may be used in the future to assess changes in incident management performance over time or to estimate the potential impacts of policy changes.

In terms of future work, more precise traffic data (e.g., collection in 1-minute intervals as opposed to 5-minute intervals) would provide greater utility with respect to the specific impacts of traffic volume and speed. Other relevant factors, such as weather and road surface condition, could also be integrated with the existing database. There was also some imprecision as to the incident location information, which was accurate to the nearest 0.1-mile. Greater precision, which could be obtained through the use of GPS, would allow for a more refined analysis.

While the effects of the aforementioned factors on incident clearance times were relatively consistent across freeways, a likelihood ratio test showed that the freeway-specific models provided superior performance to a single, joint model. Subsequent research may examine the utility of other, more flexible statistical models that allow for heterogeneous effects both within and across freeway segments. The temporal transferability of these models could also be assessed to determine how the impacts of relevant factors may change over time.

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