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Development of an Analysis Tool for Evaluation of Marginal Impacts of Freeway Incidents in the Las Vegas Area Using FAST’s Dashboard Freeway Data

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FINAL REPORT

Development of an Analysis Tool for Evaluation of Marginal Impacts of Freeway Incidents in the Las Vegas Area using FAST’s Dashboard Freeway Data

Submitted to

The Nevada Department of Transportation

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EXECUTIVE SUMMARY

Incidents are a major source of non-recurring congestion on freeways. In addition to costing millions of dollars in the loss of life, injuries and property damage, traffic incidents also cause additional losses due to the resulting traffic congestion, delay and energy consumption. Depending on the severity of an incident, in terms of the number and location of travel lanes blocked and the duration of the incident, the resulting congestion can cause significant additional traffic delays, travel time, and associated additional fuel consumption and vehicle emissions. The objective of the proposed research is to model and quantify the impacts of freeway incidents on measures of effectiveness including system-wide traffic travel times, fuel consumption and vehicle emissions. Statistical regression models are calibrated that relate freeway travel times, fuel consumption and emissions as functions of incident characteristics that include incident duration, number of lanes blocked and corresponding non-incident traffic characteristics. One year worth of data for a section of the northbound I-15 freeway in Las Vegas metropolitan area is used for the study. The data is retrieved from Dashboard, an interactive website maintained by RTC’s FAST.

Non-linear regression models are calibrated for each impact variable using the statistics software package R. Models are calibrated for (i) excess travel time per vehicle (ii) excess vehicle-hours of travel (iii) excess fuel consumption and (iv) excess vehicle emissions (CO$_2$, CO, NO$_x$ and PM$_{10}$) for all vehicles over the spatial and temporal extent of incidents. The full set of predictor variables used included incident duration, number of lanes blocked, lane-minutes of blockage (product of incident duration and number of travel lanes blocked), location of blocked lanes, ratio of lanes blocked, peak/off-peak period, day-of-week (weekday versus weekend), traffic volume, speed and density for non-incident conditions over the corresponding spatial and temporal extents of incidents.

The statistical model results indicate, as expected, that the most significant predictor variables are the incident duration, number of lanes blocked and the non-incident traffic density. In certain models, the incident duration and lanes blocked were replaced by the product of the two, namely, the lane-minutes of blockage. The resulting statistical functional forms are the Gaussian Single-Log and Double-log Generalized Linear Models (GLMs). Use of the models is demonstrated by showing examples of using the equations to compute the impact of an average incident. The results show, for example, that an average incident that has one travel lane blocked on the section of the freeway modeled results in approximately 149.2 excess vehicle-hours of travel.
and 41.45 gallon of excess fuel consumed by impacted vehicles. Further analysis using elasticity derived equations can be done to estimate marginal impacts with respect to small changes in the values of the predictor variables, such as the incident duration and number of travel lanes blocked. Such analysis can be used for planning purposes and for evaluation of the overall performance of a freeway network, as well as for benefit-cost evaluation of incident management projects.
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CHAPTER 1 : INTRODUCTION

1.1 Problem Statement

Incidents are a major source of non-recurring congestion on freeways. In addition to costing millions of dollars in the loss of life, injuries and property damage, traffic incidents also cause additional losses due to the resulting traffic congestion, delay and energy consumption. Depending on the severity of an incident, in terms of the number and location of travel lanes blocked and the duration of the incident, the resulting congestion can cause significant additional traffic delays, travel time, and associated additional fuel consumption and vehicle emissions. According to the Texas Transportation Institute’s Urban Mobility Report, traffic congestion produced an estimated cost of $121 billion of travel delay and fuel consumption in 2011 corresponding to 5.5 billion hours of extra time and 2.9 billion gallons of wasted fuel (Shrank et. al., 2012).

A number of efforts have been reported over the years that attempt to model such impacts for purposes of developing tools for evaluation of the effectiveness of incident management strategies. Most recent such studies have generally involved traffic simulation and/or theoretical models for quantifying impacts of incidents on vehicle travel times, speeds and queues formed as a result of blocked lanes due to incidents. With the existence of the extensive freeway traffic data in Las Vegas maintained by FAST and accessible online (Dashboard interactive website), this study deviates from the use of simulation models and calibrate statistical impact models using actual field historical incident and traffic data to be obtained from the website. Moreover, there is no guarantee that an impact model calibrated for traffic in one region can be transferable for use in another region due to potential differences, such driver behavior, climate, whether and other location specific variable.

1.2 Research Objective

The objective of the proposed research is to use FAST’s historical Dashboard data to model and quantify the impacts of freeway incidents on measures of effectiveness including system-wide traffic travel times, fuel consumption and vehicle emissions. Statistical regression models will be calibrated that will relate freeway travel times, speeds, energy consumption and emissions as functions of incident characteristics that include incident duration, number of lanes blocked and
time of day. The models will produce “marginal” impacts of key incident parameters, such as incident duration, traffic volumes and number and lateral location of blocked lanes, on travel times, vehicle emissions and fuel consumption. Ultimately, the goal of this study is to develop models that can be used in evaluating the effectiveness (economical or otherwise) of proposed new and/or improved incident management strategies.

1.3 Research Tasks

Overall, the research procedure involves calculating the differences in the traffic measures of performance between incident and non-incident conditions. Differences traffic performance measures are obtained for various incident conditions and statistical regression models are calibrated to obtained relationships between the incident/traffic characteristics during incidents and the resulting impacts in terms of additional travel times, fuel consumption and emissions. The project is divided into the following main tasks

1. Literature Review
2. Data Collection
3. Statistical Analysis and Model Calibration
4. Analysis of Results and Models Summary
5. Final Report

1.4 Report Organization

This report is organized in the following chapters. Chapter 2 presents a literature review of relevant technical publications and reports. Chapter 3 presents the research methodology. Chapter 4 describes the data requirements, how the data is collected and processed for analysis. Chapter 5 has descriptive summary statistics for all the impact variables with respect to variables of incident characteristics. Chapter 6 has model calibration results. In Chapter 7, marginal impact analysis is presented for each impact variable. An example application is also presented in the chapter. Finally, Chapter 8 presents conclusions and recommendations.
**CHAPTER 2 : LITERATURE REVIEW**

### 2.1 Introduction

Apart from direct costs of injury, fatalities and property damage due to incidents, there are also additional economic impacts due to increased travel times, increased fuel consumption and vehicle emissions, which have long and short term impact on the environment and quantifiable health impacts. Several previous studies have addressed different aspects of freeway incidents and their effect on freeway measures of effectiveness, such as delays and queue lengths, and other impacts such as vehicle emissions and fuel consumption. The studies have used a combination of empirical methods based on field data and/or theoretical statistical, queuing, statistical, mathematical optimization and/or computer simulation models. The papers reviewed for this study are grouped into two categories, namely, (1) those that presented procedures and/or analysis of the impact of incidents of vehicle delays, emissions and/or fuel consumption, and (2) papers that presented benefit-cost analysis studies of various freeway incident management programs.

### 2.2 Quantification of impacts of freeway incidents

Garib and Radwan (1997) presented two statistical models for predicting incident delays and estimating the impact of incidents on vehicle delays. This research was supposed to be part of the study to evaluate the impact or effectiveness of the freeway service patrol (FSP). Two months of data, one month before and one month after implementation of FSP was collected for a 7.3 mile segment of I-880 in Alameda County, California. Incident data was collected by a fleet of moving observes during the morning and evening peak periods. In addition, 30 second loop detector data was collected which included traffic speeds, flow and occupancy. Statistical regression models were then calibrated to relate the total traffic delays (in vehicle-hours) as a function of traffic and incident characteristics, including the number of lanes affected by the incident, the number of vehicles involved in the incident, the incident duration (difference between the time an incident is detected and the time it is cleared), and the traffic demand upstream of the incident in the 15 minutes before the incident starting time. They also calibrated a model for estimation of incident duration in minutes, as a function of the number of lanes affected, police response time, the number
of vehicles involved in the incident, and dummy variables for whether or not a truck (heavy vehicle) was involved, the time of day (morning vs. afternoon peaks), and weather conditions (rain or no-rain). Both sets of models were found to be statistically significant.

Xia and Chen (2007) used shockwave analysis to predict freeway travel times based on loop detector and historical incident data. The objective of the study was to develop a reliable methodology to make use of single-loop detector data and estimate travel time and the impact of incidents on travel time. Conventionally, corridor travel times have been estimated as the total of the link travel times estimated during the same time interval. Since the effects of traffic progression is not considered, the authors deemed this method as not reliable. During the time of an incident, sudden changes in flow pattern and non-recurrent congestion occur. This report focuses on estimating the effect of incident on travel time to provide accurate travel time estimation for purposes such as advanced traveler information system. The corridor selected for travel time estimation is a 9-mile freeway segment located in the Bay area of California on eastbound Interstate-80. In the methodology presented, travel time on the freeway corridor is first estimated based on short-term prediction of traffic parameters which is performed based on historical trends of the parameters without considering the impact of an incident overtly. If an incident is considered likely to have a significant impact, then the travel time is adjusted for the segment by the projected queue formed at the bottleneck. The results of this study showed that the factors that have significant impacts on the duration of an incident are day-of-week and incident type. The results also show that the trend of graph that does not consider the incident impacts on travel time usually underestimates the actual corridor travel times. After using the report’s methodology and adjusting the travel time for impact due to incident, the prediction was much closer to real-time measured values. Therefore the queuing theory-based methodology was able to capture the real-time characteristics of traffic and provide more accurate travel time estimates during an incident occurrence when compared to static methods.

Thomas and Jacko (2007) developed a stochastic model to estimate the average excess emissions of carbon monoxide (CO), volatile organic compounds (VOC), oxides of nitrogen (NO\textsubscript{X}) and particulate matter (PM\textsubscript{2.5}) and the traffic delay due to incidents. Monte Carlo simulation and statistical models of incident and traffic characteristics were used to derive the statistical characteristics of the excess emissions and traffic delays due to incidents. Data from the Borman Expressway, a heavily travelled 16-mile segment of the Interstate 80/94 freeway in Northern
Indiana was used. The study found that for the average incident with average clearance duration of 26 minutes, the average incident impact was 126.9 kg of excess CO emissions, 20.8 kg of excess VOC, and 8.8 kg of excess NOx, and 0.27 kg of excess PM2.5 emissions and 630 vehicle-hours of traffic delay.

Wang and Cheevanunothai (2008) developed an algorithm based on deterministic queuing of 1-minute loop detector data for quantifying the travel delays resulting from different categories of incidents on freeways. They used data recorded by the incident response team from the Washington State Department of Transportation (WSDOT). Since a major portion of congestion is due to traffic incidents, the research was focused on incident-related congestion and its reduction by means of management and emergency response strategies. The influence of an incident is found by comparing the delays due to different incident types. Prevalent traffic conditions were represented using a dynamic volume-based profile developed to more accurately represent non-incident scenario. VISSIM was used to validate the algorithm. Calibration was also performed to replicate the model to field conditions. It is interesting to note that the authors found that the median impact of all incidents, except non-injury commissions, was zero vehicle-hours. The median for non-injury collisions was 1.07 vehicle hours per incident. The maximum impact was 8,376 vehicle-hours. No fatal collisions were analyzed, as there were none reported during the study period. A drawback of the procedure is that it is based on a deterministic queuing technique which causes some discrepancies with the reality and that fatalities were not modeled because none occurred during the 3-month study period.

Chung and Recker (2012) presented an approach for estimating temporal and spatial extent of the delays caused by freeway accidents. The objective of the paper was to develop methods for estimating the delays as well as the spatial and temporal impacts of an incident as part of the overall goal of analysis and evaluation of incident management strategies. Another objective of the study was to identify the causal factors determining the delay of an incident. Loop detector data from six freeways in Orange County, California was used to demonstrate the method. There were no details on the incident characteristics, such as incident severity (number of lanes affected) and duration. Hence the temporal and spatial impacts of the incidents were estimated by plotting speed matrices and modeling and solving binary integer programming (BIP) problems. The methodology was employed on one-year data of a section of the freeway network in Orange County, California. The study found that for the 2,232 accidents that were studied over that time period, the median total
delay was 22.27 vehicle-hours per accident, with corresponding minimum and maximum delays of 0 and 1,379.49 vehicle hours. In addition, the study found that the variables with the most positive influence on the total delay were peak periods, 3 or more vehicles involved (function of number of vehicles involved), rear-end collision (type of collision), left lane (location of collision) and speeding (causal factors). However, no clear results were presented in the paper with respect to the temporal and spatial impacts of the incidents.

2.3 Benefit-cost studies

The following papers were selected from a number of studies whose primary objectives were to evaluate the performance and/or economic effectiveness (in terms of benefit-cost ratios) of various incident management programs. These studies generally involved “before-and-after” or “with vs without” comparative evaluations of various performance measures as a result of the incident management activities.

Skabardonis, et. al (1996) reported a study whose objectives were (1) develop a large and comprehensive database on freeway incidents and operational characteristics, (2) develop an improved methodology for estimating incident delay, and (3) apply the methodology to determine the effectiveness of freeway service patrols (FSP) at a section of freeway I-880 in the San Francisco Bay Area. Loop detector data complemented by travel time data using probe vehicles was collected for during the peak periods for 24 weekdays before and 22 weekdays after the deployment of FSPs at the test site. Information on incidents was obtained from observations of the probe vehicle drivers. A total of 1,616 incidents were observed during the study period. Deterministic queuing models were used to obtain estimates of traffic delays due to the incidents by comparing traffic data with and without incidents. The results showed deployment of FSP resulted in that a reduction of the total delay impact from 154.74 vehicle hours to 136.42 vehicle-hours per assisted incident, a reduction of 20.32 vehicle-hours per incident.

Later, Skabardonis, et. al (1998) followed-up the study above with a similar one to evaluate the effectiveness of the FSP on a 7.8 mile section of I-10 freeway (Beat 8) in Los Angeles. Field data for 32 weekdays, 6 hours per day from loop detectors and probe vehicles was used to obtain estimates of savings in performance measures in the absence of data for before FSP conditions. This 192-hour database includes detailed descriptions for 1,560 incidents. An average of 41 incidents/day was observed during the peak periods in the study area with an average duration per
incident of 20 minutes. FSP assisted 1,035 incidents during the field study (1.44 assists/truck-hr), mostly vehicles with mechanical or electrical problems, flat tires and those that had run out of gas. About 21 percent of the assists were for accidents. The average response time of FSP tow trucks was 10.8 minutes. Analysis indicated that FSP assisted incidents were shorter than non-assisted incidents by 7 to 20 minutes on the average. The estimated benefit/cost ratios based on delay and fuel savings for a range of typical reductions in incident durations was greater than 5:1. In addition, the reduction in incident duration was estimated to translate to daily reductions in air pollutant emissions of a total of 60 kg of hydrocarbons, 462 kg of carbon monoxide and 122 kg of oxides of nitrogen.

Hagen et al. (2005) evaluated the benefits of the Road Ranger freeway service patrol (FSP) program of the Florida Department of Transportation (FDOT) in terms of delay, fuel consumption and reduction of air pollution against the costs of operation, maintenance and administration of the program in the year 2004. The study used a default value of travel time of $13.45 for each person hour of travel and $71.05 for each truck hour, in accordance with the Texas Transportation Institute’s 2005 Urban Mobility report. Using an assumed occupancy and truck percentage, the average value of travel time was calculated as $22.71 per vehicle-hour. The Freeway Service Patrol Evaluation (FSPE) model developed by the University of California, Berkeley was used to estimate the savings in delay, emissions and fuel consumption (Skabardonis and Mauch, 2005). The FSPE model is implemented in a Microsoft Excel workbook using visual basic routines to evaluate impacts based on deterministic queuing models and emission sub-models to calculate reductions in emissions. Total monthly delay savings from a total of 21,759 incidents from all the sites were found to be 1,138,869 vehicle-hours of travel time and 1,717,064 gallons of fuel saved due to the FSP program, corresponding to monetary savings of $25,863,715 and $3,365,445 respectively. The B/C ratio of the entire program was found to be in excess of 25:1. Additional benefits not included in the benefit-cost (B/C) ratio calculation included monthly reductions in air pollutant emissions that were found to be 3,690 kg of reactive organic gases, 160 kg of CO and 740 kg of NOx.

Fries et al. (2007) examined the economic effectiveness of traffic cameras to detect and verify incidents at five different metropolitan freeway sites in the State of South Carolina. Various incident scenarios were simulated using Parallel Micro Simulation Software (PARAMICS) software. The authors used the MOBILE6 model developed by the Environmental Protection
Agency (EPA) for the rates of pollutant emissions and fuel consumption for vehicles moving at various speeds. Statistical tests were performed on the simulated volumes and measured volumes for the sites and it was found that there was no significant difference in the mean and variance of measured and simulated volume for both freeway and arterial links. The costs considered for economic analyses were: service and maintenance, communication, infrastructure, and personnel. The benefits were categorized as savings in: vehicle delays, energy consumption and air pollution (CO emissions, NO\textsubscript{x} emissions, HC emissions, PM). The dollar values were found using Intelligent Transportation Systems (ITS) Deployment Analysis System (IDAS). The incident scenarios were compared to the base scenarios and the differences were attributed to the incident. The study found that use of the cameras reduced vehicle delays by 5.2% and fuel consumption by 3.8% (diesel) and 3.2% (unleaded gasoline). Total hydrocarbons and volatile organic compounds were both reduced by approximately 14%, carbon monoxide by almost 10%, nitrous oxide by almost 7%, and particulate matter by approximately 1% corresponding to 35 kg/day of hydrocarbons, 195 kg/day of carbon monoxide, and 40 kg/day of nitrous oxides respectively. A benefit-cost analysis based on the simulation results suggested traffic cameras returned $12 for every dollar spent under the prevailing conditions at the study sites.

Dougald and Demetsky (2008) developed methods to quantify the benefits of safety service patrols (SSPs) for the Northern Virginia region. The procedure developed included determining incident durations with and without SSPs and applying the results to the Freeway Service Patrol Evaluation (FSPE) model to quantify the benefits resulting from the reduced traffic delays attributable to SSPs. The FSPE model uses deterministic queuing models to estimate traffic delays associated with queues that form during incident conditions (Skabardonis and Mauch, 2005). The models takes as input the geometric and traffic characteristics of the route, and the type and frequency of SSP assisted incidents. From one of the area freeway analyzed, the results indicated an overall average reduction in incident duration of 17.3% with associated savings of 290,765 vehicle-hours and 438,598 gallons of fuel resulting in total benefits of approximately $6,488,126. With a corresponding SSP cost of $1,193,511, this represented a B/C ratio of 5.4:1. As expected, the savings were a function of the type of incident, traffic characteristics and time of day.

Chou, Miller-Hooks and Promisel (2010) did a benefit-cost analysis of the effectiveness of the freeway service patrol within New York State, known as the “Highway Emergency Local
Patrol (H.E.L.P.)”. They performed a CORSIM simulation-based study for a 10-mile segment of the freeway network and found that there was an average reduction of 20 minutes in the duration of each incident, i.e., incidents were being cleared faster due to the prompt arrival and service of H.E.L.P. personnel. This resulted in estimated annual savings of 24,000 vehicle-hours of travel delay, 2,900 gallons of fuel consumed, 0.32 tons of hydrocarbons (HC), 3.6 tons of carbon monoxide (CO), 0.2 tons of nitrogen oxide and 18 secondary incidents. These are very significant economic as well as environmental benefits and a benefit-cost analysis clearly showed justification for use of the funds for the H.E.L.P. program.

2.4 Summary

Table 1 below provides a summary of selected incident impact studies. In general, these studies, with the exception of the one by Garib and Radwan (1997), only reported average or aggregate measures for the impact of incidents on traffic delays, travel times, emissions and/or fuel consumption. The results from these studies may not be usable in analysis of incremental improvements in incident management activities. None of the studies have reported “marginal” impacts of, for example, reduction in incident duration, or number of blocked lanes. Also, most of these studies used a combination of field data as well as theoretical models and simulation models of traffic performance measures, such as queue lengths, which limits their ability to more accurately reproduce real world conditions. Garib and Radwan (1997) came closest to answering these issues, however, the study was based on only two-months’ worth of data and analysis was during the peak periods only. They also did not evaluate vehicle emissions or fuel consumption. Overall, one can also observe from these studies the wide range in reported measures of impacts per incident, reflecting the regional differences as well as methodologies used in the analysis.
**Table 2-1: Summary of Selected Incident Impact Studies**

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Setting and methodology</th>
<th>Modeling delays, emissions and fuel Consumption</th>
<th>Impact Results</th>
</tr>
</thead>
</table>
| Skabardonis, et. Al (1996) | California’s I-880 Freeway; 250 hours of detector data (speeds, flow, occupancy); Travel times, and incident data collected using probe vehicles; 1,616 incidents; | Incident delays – deterministic queuing analysis used to estimate delays and recorded difference in travel speeds with/without incidents | Without FSP, impact per assisted incident: 156.74 veh-hrs  
With FSP, 136.42 veh-hrs, savings of 20.32 veh-hrs per incident  
No regression models. |
| Hagen, Larry; Zhou, Huaguo and Singh, Harkanwal. (2005) | FL Road Ranger FSP Program | California’s Freeway Service Patrol Evaluation (FSPE) software  
Travel Time value: Texas Transportation Institute (TTI) | Total monthly delay savings of 1,138,869 vehicle-hours of travel time, and 1,717,064 gallons of fuel consumed  
3,690 kg of reactive organic gases, 160 kg of CO and 740 kg of NOx. |
| Thomas, Salimol and Jacko, Robert B. (2007) | Study area was a 3-lane highway with 6,000 vph capacity and 10,000 incidents | Monte Carlo simulation was used to derive statistical characteristics of excess emissions and traffic delays | Each incident averages 126.9 kg of excess CO, 20.8 kg of VOC, 8.8 kg of NOx, 0.27 kg of PM$_{2.5}$ and 630 vehicle-hours  
This corresponds to 500%, 26% and 43% of increase in VOC, NOx and PM$_{2.5}$ respectively when compared with normal traffic conditions. |
Table 2.1: Summary of Selected Incident Impact Studies (Continued…..)

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Setting and methodology</th>
<th>Modeling delays, emissions and fuel Consumption</th>
<th>Impact Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dougald, Lance E. and Demetsky, Michael J. (2008)</td>
<td>Northern Virginia Interstates 395, 495, 96, 66 and State Route 267, a total of 198 centerline miles. Study period of 1 year with a total of 22,233 incidents.</td>
<td>Delays: Queuing models to estimate queues and delays Emissions: MOBILE6</td>
<td>Average reduction in incident duration of 17.3% with associated annual delay savings of 290,765 veh-hrs and 438,598 gallons of fuel; Emissions savings of 36,614 kg ROG (reactive organic gases), 1,934 kg CO and 8,153 kg NOx</td>
</tr>
<tr>
<td>Chou, Chihsheng; Miller-Hooks, Elise and Promisel, Ira (2010)</td>
<td>CORSIM-simulation-based study for a 10-mile segment of the freeway network; NY HELP program</td>
<td>Delays and Fuel Consumption: CORSIM Emissions: Rates from Maryland DOT</td>
<td>Average reduction of 20 minutes in the duration of each incident; Estimated annual savings of 24,000 veh-hrs of travel delay, 2,900 gallons of fuel consumed, 0.32 tons of hydrocarbons (HC), 3.6 tons of carbon monoxide (CO), 0.2 tons of nitrogen oxide, and 18 secondary incidents</td>
</tr>
</tbody>
</table>
CHAPTER 3 : METHODOLOGY

3.1 Introduction

This chapter presents the methodology for modeling the impacts of incidents. In this study, only the impacts of vehicular incidents are considered. The impacts on the opposing direction of traffic due to rubbernecking are also added to the impacts of the primary analysis direction. The term rubbernecking is used to describe the phenomenon where the drivers in one direction of flow are distracted by an incident (and queues) in the opposing direction of flow (Masinick and Teng, 2004). Since the effect is caused due to the incident in the primary direction of flow, the resulting rubbernecking impacts are also added as additional components while computing incident impacts.

3.2 Impacted Measures of Performance

In this study, impacts of incidents on travel time, fuel consumption and vehicle emissions are modeled. The following is a description of these measures of performance.

3.2.1 Travel Time

One of the impacts of incidents is increased travel time for vehicles travelling on the impacted segment. The travel time measures used in this study are vehicle-hours of travel, and additional average vehicle travel time over the freeway segment impacted by the incident. The excess of travel time performance measures caused due to traffic incidents is measured by comparing travel time during non-incident and incident conditions.

3.2.2 Fuel Consumption

Another impact of incidents is excess fuel consumption due to reduced vehicle speeds and increased travel time. Figure 3-1 shows the effect of speed on fuel economy with lower and higher speeds indicating reduced fuel economy (USDOE, 2005). Traffic incidents and the ensuing congestion cause lower speeds, therefore resulting in lower fuel economy as shown by Figure 3-1. In this study, EPA’s MOVES software is used to estimate the increase in fuel consumption of the impacted vehicles. The excess fuel consumption is computed as the difference between the fuel consumption during incident and non-incident traffic conditions.
3.2.3 Vehicle Emissions

Based on the literature review of related studies and publications, the emission pollutants chosen to be considered in this study are Carbon Dioxide (CO$_2$), Carbon Monoxide (CO), Oxides of Nitrogen (NO$_x$) and Particulate Matter of size 10 micrometers or less, (PM$_{10}$). Vehicular traffic has been found to be a significant contributor to the production of these three pollutants (Rodrigue, 2013). Transportation industry is the highest contributor accounting to about 70% of CO, 40% of NO$_x$ and 25% of PM$_{10}$ production respectively. Oxides of nitrogen contribute to illnesses and react with the atmosphere to affect ozone levels. Also, a component of NO$_x$ namely NO$_2$ is toxic. PM$_{10}$ causes respiratory illnesses and CO causes oxygen deprivation in human body leading to numerous other illnesses (Gorham, 2002).

Vehicle emissions vary with the speed of vehicle and type of vehicle. Figures 3-2, 3-3 and 3-4 from the California Life-Cycle Benefit Cost Analysis Model (Cal-B/C) show the CO, NO$_x$ and Particulate Matter less than 10 micrometers (PM$_{10}$) emissions by speed based on UCLA speed measurements for 2003 and 2007 on a highway facility (System Metrics Group, Inc., 2009). The figures show emissions for three types of vehicles, automobiles, buses and trucks, for a highway facility. Traffic incidents can be expected to cause increased emissions due to resulting low operating speeds and sudden acceleration and deceleration.

Figure 3-1. Fuel Economy and Speed (Source: USDOE)
Figure 3-2. CO Emissions versus Speed
(System Metrics Group, Inc., 2009)

Figure 3-3. NO\textsubscript{x} Emissions versus Speed
(System Metrics Group, Inc., 2009)
As seen in the figures, very low and very high speeds result in higher emissions when compared to normal speeds. The vehicle emissions in this study are modeled using EPA’s MOVES for the incident and non-incident scenarios and the difference between the two is computed as the excess vehicle emissions produced due to that incident.

### 3.3 Study Methodology

The flowchart in Figure 3-5 presents the overall methodology for computing the impacts considered in this study - travel time, fuel consumption and vehicle emissions.

#### 3.3.1 Sample Selection

The first step in the process is the selection of a suitable sample of incidents from the incident database. All the incidents that occurred in a one-year period are used as the population.
Proportional sampling is performed to ensure that the sample has the same proportion of incidents, segment-wise, as the population. After performing proportional sampling on this data, a sample subset is chosen at random according to the requirement for each segment.

![Flowchart for Modeling Incident Impacts on Travel Time, Emissions and Fuel Consumption](image)

**Figure 3-5. Flowchart for Modeling Incident Impacts on Travel Time, Emissions and Fuel Consumption**

### 3.3.2 Generation of Analysis Database

The flowchart for generation of the analysis database is shown in Figure 3-6.
1. Record incident details

2. Determine spatial and temporal impact extents

3(a) Incident Data
   Compute VHT, VMT, travel time, emissions, and fuel consumption for incident impact extent (primary, rubbernecking)

3(b) Non-Incident Data
   Compute VHT, VMT, travel time, emissions, and fuel consumption for corresponding impact extent (primary, rubbernecking)

4. Compute impact VHT, VMT, additional travel time, emissions and fuel consumption for Primary and Rubbernecking directions

Update the database

More incidents in sample set?

Yes

No

Database Complete

Figure 3-6. Flowchart for Generation of the Analysis Database
Step 1. Recording incident characteristics.

This step is to record the incident characteristics from the incident database. Table 3-1 shows sample incident information for which the procedure for computation of the impact on delay is explained. The incident characteristics recorded include day of week, time of day, location, number of lanes blocked, incident duration, presence of a secondary crash and severity of the incident.

<table>
<thead>
<tr>
<th>Time Stamp</th>
<th>Corridor</th>
<th>Location</th>
<th>Lanes Blocked</th>
<th>Number of lanes</th>
<th>Lane Cleared</th>
<th>Time Elapsed (min)</th>
<th>Secondary</th>
<th>Severity</th>
<th>Roadway ID</th>
<th>Segment ID</th>
</tr>
</thead>
</table>

11:26:00 AM     | 1:02:00 PM

Step 2. Determination of spatial and temporal extents of the incident

This step involves the collection and plotting of speeds for the incident day in order to determine how far upstream the incident had impact (spatial extent) and the total time period impacted (temporal extent). Figure 3-7 shows a typical plot of speeds of the day of an incident under consideration from which the spatial and temporal extents are clearly evident.

The following parameters are extracted from this data, namely,

i. Duration of temporal extent (in minutes), i.e., how long after the occurrence of the incident is the impact felt

ii. Length of spatial extent (in miles), i.e., how far upstream does the incident-induced congestion extend
Step 3. Computing VHT, VMT, travel time, emissions, and fuel consumption for impact extent

a) This step involves the calculation of the traffic parameters for incident condition over the corresponding spatial and temporal extent of the incident. The parameters to be determined include traffic volumes, speeds, travel times, and densities over each segment and time period covering the spatial and temporal extents. Similar data in opposite direction is obtained for the impact of rubbernecking. The following parameters are calculated for the corresponding segments and time periods covered in the spatial and temporal extents.

Volume,

\[ V_{k,t} = v_{k,t} \frac{60}{T} \]  

(3-1)

Average volume,

\[ VOL_j = \frac{\sum_{t=1}^{N_t} \sum_{k=1}^{N_k} V_{k,t} L_k}{\sum_{k=1}^{N_k} L_k} \text{ vph} \]  

(3-2)
Average volume per lane, \( \text{vol}_{j} = \frac{\sum_{i=1}^{N_e} \sum_{k=1}^{N_k} V_{i,k,j} L_k}{\sum_{k=1}^{N_k} L_k} \) vphpl \hspace{1cm} (3-3)

Average travel speed, \( \text{SPD}_{j} = \frac{\sum_{i=1}^{N_e} \sum_{k=1}^{N_k} S_{i,k,j} L_k}{\sum_{k=1}^{N_k} L_k} \) mph \hspace{1cm} (3-4)

Density, \( D_{k,j} = \frac{V_{k,j}}{S_{k,j}} \) vpm \hspace{1cm} (3-5)

Average density per lane, \( \text{DEN}_j = \frac{\sum_{i=1}^{N_e} \sum_{k=1}^{N_k} D_{i,k,j} L_k}{\sum_{k=1}^{N_k} L_k} \) vpmpl \hspace{1cm} (3-6)

Total travel time over impacted segments, \( \text{TT}_{j} = \frac{1}{N_T} \sum_{i=1}^{N_e} \sum_{k=1}^{N_k} T_{i,k,j} \) minutes \hspace{1cm} (3-7)

Vehicle-hours-of-travel, \( \text{VHT}_{j} = \frac{1}{60} \sum_{i=1}^{N_e} \sum_{k=1}^{N_k} v_{i,k,j} TT_{i,k,j} \) \hspace{1cm} (3-8)

Vehicle-miles-of-travel, \( \text{VMT}_j = \sum_{i=1}^{N_e} \sum_{k=1}^{N_k} v_{i,k,j} L_k \) \hspace{1cm} (3-9)

Rate of fuel consumption and vehicle emissions, \( \dot{f}_e_{j} = \frac{FE_{x,j}}{VMTM_j} \) \hspace{1cm} (3-10)

Where \( N_K \) = the total number of segments over the spatial extent of the incident
$L_k = \text{length of segment } k \text{ in miles}$

$M_k = \text{the number of lanes on segment } k$

$T = \text{length of time period } t \text{ in minutes}$

$N_T = \text{the total number of time periods over the temporal extent (each time period is approximately 15 minutes)}$

$v_{k,t} = \text{number of vehicles on segment } k \text{ during time period } t$

$V_{k,t} = \text{volume on segment } k \text{ during time period } t \text{ in vph}$

$S_{k,t} = \text{speed, in mph, on segment } k \text{ during time period } t$

$D_{k,t} = \text{density, in vpm, on segment } k \text{ during time period } t$

$TT_{k,t} = \text{travel time, in minutes, on segment } k \text{ during time period } t$

$FE_{x,j} = \text{output from MOVES in grams for emissions and gallons for fuel}$

$x = \text{factor estimated using MOVES: fuel and emissions (CO}_2, \text{ CO, NO}_x, \text{ PM}_{10})$

$j = \text{used to distinguish between incident and non-incident parameters and the primary and rubbernecking direction}$

$VMTM_j = \text{vehicle-miles of travel estimated by MOVES}$

b) For each incident, corresponding non-incident traffic parameters are collected for the same day-of-week, spatial and temporal extent as the incident using the same formulae mentioned above. The days-of-week are divided into four, namely, weekdays (Monday – Thursday), Fridays, Saturdays and Sundays. The non-incident parameters are computed averages over several days’ worth of non-incident time periods for corresponding day of week.

The entire process is to be repeated for the rubbernecking direction as well, for the same temporal and spatial extent (plus an extra segment upstream in the rubbernecking direction).
Step 4. Computing impact VHT, VMT, additional travel time, emissions and fuel consumption

In this step, the following incident impact parameters are calculated for each incident:

a) Average additional travel time: This is the difference between the incident and non-incident average total travel time over the all the segments in the spatial and temporal extents, i.e.,

\[ \Delta TT = (TT_{inc} - TT_{non}) \]  
\[ \Delta TT_R = (TT_{Rinc} - TT_{Rnon}) \]

where

\( TT_{inc} \) and \( TT_{non} \) are incident and non-incident travel times, respectively.

\( TT_{Rinc} \) and \( TT_{Rnon} \) are incident and non-incident travel times for the rubbernecking direction, respectively.

b) The additional vehicle-hours-of-travel and vehicle-miles of travel are calculated as follows, i.e.,

\[ \Delta VHT = \sum_{t=1}^{N_t} \sum_{k=1}^{N_k} V_{t,k} \Delta TT \]  
\[ \Delta VHT_R = \sum_{t=1}^{N_t} \sum_{k=1}^{N_k} V_{R,t,k} \Delta TT_{R} \]

\[ \Delta VMT = VMT_{inc} - VMT_{non} \]

\[ \Delta VMT_R = VMT_{Rinc} - VMT_{Rnon} \]

where

\( VMT_{inc} \) and \( VMT_{non} \) are vehicle-miles of travel for the incident and non-incident condition, respectively.

\( VMT_{Rinc} \) and \( VMT_{Rnon} \) are vehicle-miles of travel for the incident and non-incident condition in the rubbernecking direction, respectively.

c) The additional fuel consumption in gallons/vehicle miles is computed by running EPA’s MOVES software for incident and non-incident conditions and calculating the difference in fuel consumed per vehicle mile.
\[ \Delta_{\text{fuel}} = (VMT_{\text{inc}}(fe_{\text{fuel,inc}} - fe_{\text{fuel,non}}) + VMT_{\text{Rinc}}(fe_{\text{fuel,Rinc}} - fe_{\text{fuel,Rnon}})) \]  

(3-17)

where

\( fe_{\text{fuel,inc}} \) and \( fe_{\text{fuel,non}} \) are incident and non-incident fuel consumption rates in gallons per mile respectively.

\( fe_{\text{fuel,Rinc}} \) and \( fe_{\text{fuel,Rnon}} \) are incident and non-incident fuel consumption rates in gallons per mile respectively for the rubbernecking direction.

d) The additional emissions in grams/vehicle miles are similarly determined by running EPA’s MOVES software for incident and non-incident conditions and calculating the difference.

\[ \Delta_{\text{emissions}} = (VMT_{\text{inc}}(fe_{\text{emissions,inc}} - fe_{\text{emissions,non}}) + VMT_{\text{Rinc}}(fe_{\text{emissions,Rinc}} - fe_{\text{emissions,Rnon}})) \]  

(3-18)

where

\( fe_{\text{emissions,inc}} \) and \( fe_{\text{emissions,non}} \) are incident and non-incident emissions in grams per mile respectively.

\( fe_{\text{emissions,Rinc}} \) and \( fe_{\text{emissions,Rnon}} \) are incident and non-incident emissions in grams per mile respectively for the rubbernecking direction.

The above procedure is repeated for all incidents considered and corresponding databases are generated.

### 3.3.3 Statistical Modeling

Regression models are calibrated to obtain the relationship between incident characteristics, such as the duration of blockage and the number of lanes blocked, and the impact on performance measures, such as the average travel time, vehicle-hours-of-travel, fuel consumption and vehicle emissions. These models are then used to estimate marginal impact of the incident parameters. For example, they can be used to estimate the impact on VHT for each additional minute of block duration, or for each lane blocked during an incident. Using Minitab and R statistical packages, regression analysis based on the following functional forms is performed.
**Linear Regression Models**

Linear regression models the mean value of the dependent variable as a linear function of the independent variables. This model is appropriate for analyzing dependent variables that are continuous and normally distributed.

\[
Y_d = \beta_0 + \sum_{j=1}^{N} \beta_j X_j
\]  

(3-19)

Where:

- \(Y_d\) = impact on an MOE parameter, such as VHT, travel time, fuel consumption, or emissions
- \(\beta_j\) = regression coefficient for variable \(j\)
- \(X_j\) = predictor/independent variable \(j\)

**Log-Transformed Regression Models**

An exponential regression uses an equation of the exponential function to fit a set of data. Exponential regression model takes the form:

\[
Y_d = \text{Exp} \left( \beta_0 + \sum_{j=1}^{N} \beta_j X_j \right)
\]  

(3-20)

In this analysis an exponential relationship between the dependent and independent variables is subjected to linear transformation by taking logarithm on both sides. This model changes the dependent variable and interpretation should be changed accordingly.

**Generalized Linear Models**

Generalized Linear Models (GLM) models relate the mean of a dependent variable to a linear combination of explanatory variables while allowing for non-constant variance. A generalized linear model is made up of a linear function and two other functions: a link function that describes how the mean depends on the linear predictor, and a variance function that describes how the variance depends on the mean. GLMs are fit to data by the method of maximum likelihood, which is different from the Ordinary Least Squares method used by regular linear models. These models are useful when the dependent variable does not follow normal distribution.
Linear Models: \( E(y_d) = \mu_d = \beta_j X_j \) where \( y_d \sim N(\mu, \sigma^2) \)

GLMs: \( E(y_d) = \mu_d = \gamma(\beta_j X_j) \) where \( y_d \sim \text{Exponential Family} \)  

Where, \( \gamma \) is the link function.

The exponential family of distributions can include distributions such as Poisson, Gaussian (normal), binomial and gamma. GLMs of the Gaussian and Gamma families are modeled in this study. For the Gamma GLM the link used in inverse and therefore the general model is of the form:

\[
Y = (\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p)^{-1}
\]

Minitab software is used for development of the descriptive statistics of the data, their histograms, box plots and correlation matrices. R software is used for calibrating the linear, exponential and GLM models. These software packages are chosen owing to their ability to perform the required analysis and ease of use. Stepwise regression is used to determine the most significant variables, while taking into account the correlation between the predictor variables. A confidence interval of 95% is used to evaluate the statistical significance.

### 3.3.4 Model Selection

The full model with all the predictor variables is modeled for each of the LMs and GLMs. A nested model is selected by using Adjusted \( R^2 \), Akaike Information Criteria (AIC) and stepwise regression, with the variables being significant at \( \alpha = 0.05 \). The coefficient of determination \( R^2 \) is an indicator of how well the model fits the set of data. In general, a higher \( R^2 \) signifies a good model. AIC is another parameter to measure goodness of fit and is applicable to GLM models (Burham and Anderson, 1998). These methods are used, whenever appropriate to select the appropriate regression model in this study. Once the final nested models for each of the functional forms of the LMs and GLMs are modeled, the residual plots are compared to select the best model. The selection of the best model depends upon the list of variables present in the model and its fit.

### 3.3.5 Marginal Impact Analysis

The final nested model selected is then used to interpret and determine the marginal impact of the predictor variables on the response variable. The marginal impact analysis is used to determine the rate of change of incident impact (e.g., excess VHT) with percentage or unit change in incident characteristics such as incident duration and number of lanes blocked.
4.1 Introduction

In accordance with the methodology described in Chapter 3, the data required for impact analysis include incident data and traffic characteristics. The Regional Transportation Commission of Southern Nevada’s Freeway and Arterial System of Transportation (RTC FAST) maintains a web-based system called the PMMS Dashboard which keeps historical incident and traffic data for the Las Vegas valley freeway system (Xie and Hoeft, 2012) in a wide variety of customizable displays for evaluating day-to-day operation, incident management, express lane evaluation, ramp meters operation, ITS devices maintenance and operation data quality control. This Dashboard is the main source of data for this research.

4.2 Data Description and Collection

4.2.1 Incident Data

The incident database on the Dashboard is a consolidated historical database of all the reported incidents on Las Vegas freeways, including the Interstate 15 (I-15). The I-15 carries a lot of local commuter traffic in and out of the resort corridor from the suburbs. Even though incident information for all the freeways was available from FAST, the I-15 was chosen since the corresponding traffic data was more comprehensive in terms of data entry, when compared to the other freeways. The map of the study location is shown in Figure 4-1.
The following summarizes the study area parameters:

a. Study area: I-15 NB from St Rose to the Speedway.
c. Time of Day: 5 AM – 9 PM. Nighttime was left out because most freeway maintenance activities are conducted at night, and there is lack of reliable data on workzone schedules. In any case, due to low traffic volumes at night, the impact of incidents is expected to be much lower compared to daytime conditions.

During this study period, I-15 NB had 674 incidents and SB had 399 distributed by location as shown in Figure 4-2. The data shows that the segment between Sahara Avenue and Charleston Boulevard had the most number of the incidents. Also, the northbound direction had more number
of incidents than the corresponding southbound direction. The primary segment in this analysis is the Northbound direction, with the impacts on the rubbernecking direction (SB) included in the analysis. Figures 4-3 and 4-4 show the crash distribution by day of week and time of day.

Figure 4-2. Number of Incidents by Segment

Figure 4-5 shows a typical Dashboard report with some incidents that occurred on December 30-31, 2011.
Figure 4-3. Number of Incidents by Day of Week

Figure 4-4. Number of Incidents by Time of Day
<table>
<thead>
<tr>
<th>Time Stamp</th>
<th>Corridor</th>
<th>Location</th>
<th>Lanes Blocked</th>
<th>Number of Lanes</th>
<th>Tow Truck Arrive</th>
<th>Time Elapsed (min)</th>
<th>Lane Cleared</th>
<th>Time Elapsed (min)</th>
<th>Secondary</th>
<th>Severity</th>
<th>Message</th>
<th>Roadway ID</th>
<th>Segment ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/31/2011 5:40:00 PM</td>
<td>US-95 SB</td>
<td>Ann Rd</td>
<td>right lane</td>
<td>1</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>negligible</td>
<td>12/31/2011 5:40 PM, Crash on US-95 Southbound at Ann Rd, right lane blocked, Expect delays</td>
<td>411</td>
<td>1</td>
</tr>
<tr>
<td>12/30/2011 6:31:00 PM</td>
<td>I-15 SB</td>
<td>Charleston</td>
<td>right shoulder</td>
<td>0</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td>negligible</td>
<td>12/30/2011 6:31 PM, Crash on I-15 Southbound at Charleston, right shoulder blocked</td>
<td>117</td>
<td>1</td>
</tr>
<tr>
<td>12/30/2011 5:40:00 PM</td>
<td>I-15 NB</td>
<td>north of Sahara</td>
<td>right lanes</td>
<td>2</td>
<td>12/30/2011 6:02:00 PM</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td>significant</td>
<td>12/30/2011 5:40 PM, Crash on I-15 Northbound north of Sahara, right lanes blocked</td>
<td>110</td>
<td>1</td>
</tr>
<tr>
<td>12/30/2011 5:07:00 PM</td>
<td>I-15 NB</td>
<td>north of Sahara</td>
<td>right shoulder</td>
<td>0</td>
<td>12/30/2011 5:52:00 PM</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td>negligible</td>
<td>12/30/2011 5:07 PM, Crash on I-15 Northbound north of Sahara, right shoulder blocked</td>
<td>110</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 4-5. Typical Incident Report Page from Dashboard
The following incident details were used in this study:

- Day of the week of occurrence of the incident
- Time of day of occurrence of the incident
- Location of segment on which incident occurred
- Time the incident was cleared: The time duration between the time the incident occurred and when it was cleared gives the incident duration.
- The number of travel lanes-blocked by the incident
- Location of blocked lanes, i.e., left, center, right or shoulder lanes
- Presence of a secondary crash: If an incident occurred in the wake of the congestion of another incident. If the latter incident is within the temporal and spatial extent of the former incident, the latter is termed as a secondary incident.

From the incident data, a random sample of incidents to be used for the study is selected based on proportional sampling by incident location. An additional criterion in the proportional sampling is that each segment should have at least one incident in the study sample. Column 6 in Table 4-1 shows the number of incidents from each segment in the incident database and the corresponding sample size selected for the study. From each segment, the required number of incidents is selected at random. There are a total of 203 incidents in the study sample. The process of sampling the 203 incidents also included a criteria that for each selected incident, there is no incident in the opposite direction at around the same time and location as the selected incident. This is to ensure that the impact observed is only for the primary incident, and not a possible incident in the adjacent opposite direction.

One of the problem with the incident data that was acquired was that about 30% of them did not have incident duration recorded. In such cases, the duration was estimated manually by examining the individual speed and traffic volume data.
Table 4-1. Number of Incidents for each Freeway Segment in the Study Area (I-15 NB)

<table>
<thead>
<tr>
<th>Roadway-Segment ID</th>
<th>Seq ID</th>
<th>Segment</th>
<th>I-15 NB</th>
<th>Proportion</th>
<th>Sample Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>356-2</td>
<td>56</td>
<td>Silverado Ranch</td>
<td>0</td>
<td>0.0000</td>
<td>0</td>
</tr>
<tr>
<td>356-3</td>
<td>57</td>
<td>past Silverado Ranch</td>
<td>1</td>
<td>0.0015</td>
<td>1</td>
</tr>
<tr>
<td>355-1</td>
<td>58</td>
<td>past Silverado Ranch</td>
<td>0</td>
<td>0.0000</td>
<td>0</td>
</tr>
<tr>
<td>355-3</td>
<td>60</td>
<td>before Blue Diamond</td>
<td>0</td>
<td>0.0000</td>
<td>0</td>
</tr>
<tr>
<td>354-1</td>
<td>61</td>
<td>before Blue Diamond</td>
<td>0</td>
<td>0.0000</td>
<td>0</td>
</tr>
<tr>
<td>354-2</td>
<td>62</td>
<td>Blue Diamond</td>
<td>0</td>
<td>0.0000</td>
<td>0</td>
</tr>
<tr>
<td>354-3</td>
<td>63</td>
<td>past Blue Diamond</td>
<td>1</td>
<td>0.0015</td>
<td>1</td>
</tr>
<tr>
<td>32-2</td>
<td>65</td>
<td>past Blue Diamond</td>
<td>0</td>
<td>0.0000</td>
<td>0</td>
</tr>
<tr>
<td>34-2</td>
<td>67</td>
<td>before I-215 Interchange (Southern Beltway)</td>
<td>2</td>
<td>0.0030</td>
<td>1</td>
</tr>
<tr>
<td>39-2</td>
<td>68</td>
<td>I-215 Interchange (Southern Beltway)</td>
<td>2</td>
<td>0.0030</td>
<td>1</td>
</tr>
<tr>
<td>48-2</td>
<td>69</td>
<td>past I-215 Interchange (Southern Beltway)</td>
<td>18</td>
<td>0.0267</td>
<td>5</td>
</tr>
<tr>
<td>49-1</td>
<td>70</td>
<td>before Russell Road</td>
<td>5</td>
<td>0.0074</td>
<td>2</td>
</tr>
<tr>
<td>49-2</td>
<td>71</td>
<td>Russell Road</td>
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<td>1</td>
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<tr>
<td>49-3</td>
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<td>Russell Road</td>
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<td>0.0223</td>
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</tr>
<tr>
<td>58-2</td>
<td>73</td>
<td>before Tropicana Ave</td>
<td>25</td>
<td>0.0371</td>
<td>7</td>
</tr>
<tr>
<td>59-1</td>
<td>74</td>
<td>Tropicana Ave</td>
<td>8</td>
<td>0.0119</td>
<td>3</td>
</tr>
<tr>
<td>59-2</td>
<td>75</td>
<td>Tropicana Ave</td>
<td>9</td>
<td>0.0134</td>
<td>3</td>
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<td>70-2</td>
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<td>before Flamingo Rd</td>
<td>26</td>
<td>0.0386</td>
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</tr>
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<td>7</td>
</tr>
<tr>
<td>89-2</td>
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<td>Spring Mountain</td>
<td>14</td>
<td>0.0208</td>
<td>4</td>
</tr>
<tr>
<td>97-1</td>
<td>82</td>
<td>past Spring Mountain</td>
<td>18</td>
<td>0.0267</td>
<td>5</td>
</tr>
<tr>
<td>97-2</td>
<td>83</td>
<td>Desert Inn</td>
<td>11</td>
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<td>3</td>
</tr>
<tr>
<td>97-3</td>
<td>84</td>
<td>before Sahara</td>
<td>50</td>
<td>0.0742</td>
<td>14</td>
</tr>
<tr>
<td>99-1</td>
<td>85</td>
<td>Sahara</td>
<td>116</td>
<td>0.1721</td>
<td>32</td>
</tr>
<tr>
<td>110-1</td>
<td>86</td>
<td>past Sahara</td>
<td>181</td>
<td>0.2685</td>
<td>49</td>
</tr>
<tr>
<td>112-2</td>
<td>87</td>
<td>before Charleston</td>
<td>45</td>
<td>0.0668</td>
<td>13</td>
</tr>
<tr>
<td>113-2</td>
<td>88</td>
<td>Charleston</td>
<td>15</td>
<td>0.0223</td>
<td>5</td>
</tr>
<tr>
<td>122-2</td>
<td>89</td>
<td>past Charleston</td>
<td>15</td>
<td>0.0223</td>
<td>5</td>
</tr>
<tr>
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<td>90</td>
<td>US 95 Interchange</td>
<td>8</td>
<td>0.0119</td>
<td>3</td>
</tr>
<tr>
<td>137-1</td>
<td>92</td>
<td>past US 95 Interchange</td>
<td>2</td>
<td>0.0030</td>
<td>1</td>
</tr>
<tr>
<td>138-1</td>
<td>93</td>
<td>D Street</td>
<td>2</td>
<td>0.0030</td>
<td>1</td>
</tr>
<tr>
<td>138-2</td>
<td>94</td>
<td>Washington Ave</td>
<td>4</td>
<td>0.0059</td>
<td>2</td>
</tr>
<tr>
<td>146-2</td>
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<td>Owens Ave</td>
<td>3</td>
<td>0.0045</td>
<td>1</td>
</tr>
<tr>
<td>148-2</td>
<td>97</td>
<td>Lake Mead Blvd</td>
<td>2</td>
<td>0.0030</td>
<td>1</td>
</tr>
<tr>
<td>149-2</td>
<td>98</td>
<td>past Lake Mead Blvd</td>
<td>2</td>
<td>0.0030</td>
<td>1</td>
</tr>
<tr>
<td>160-2</td>
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<td>0</td>
</tr>
<tr>
<td>396-1</td>
<td>102</td>
<td>before Cheyenne</td>
<td>2</td>
<td>0.0030</td>
<td>1</td>
</tr>
<tr>
<td>396-2</td>
<td>103</td>
<td>before Cheyenne</td>
<td>1</td>
<td>0.0015</td>
<td>1</td>
</tr>
<tr>
<td>396-3</td>
<td>104</td>
<td>Cheyenne</td>
<td>3</td>
<td>0.0045</td>
<td>1</td>
</tr>
<tr>
<td>397-1</td>
<td>105</td>
<td>past Cheyenne</td>
<td>1</td>
<td>0.0015</td>
<td>1</td>
</tr>
<tr>
<td>398-1</td>
<td>108</td>
<td>before Craig Road</td>
<td>3</td>
<td>0.0045</td>
<td>1</td>
</tr>
<tr>
<td>398-2</td>
<td>109</td>
<td>before Craig Road</td>
<td>1</td>
<td>0.0015</td>
<td>1</td>
</tr>
<tr>
<td>399-2</td>
<td>112</td>
<td>past Craig Road</td>
<td>0</td>
<td>0.0000</td>
<td>0</td>
</tr>
<tr>
<td>400-1</td>
<td>114</td>
<td>Lamb Blvd</td>
<td>2</td>
<td>0.0030</td>
<td>1</td>
</tr>
<tr>
<td>402-1</td>
<td>120</td>
<td>CC 215 (Northern Beltway)</td>
<td>1</td>
<td>0.0015</td>
<td>1</td>
</tr>
<tr>
<td>403-3</td>
<td>125</td>
<td>Speedway</td>
<td>0</td>
<td>0.0000</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td></td>
<td></td>
<td>674</td>
<td>203</td>
<td></td>
</tr>
</tbody>
</table>
4.2.2 Traffic Data

Data regarding traffic characteristics are also obtained from RTC FAST’s PMMS Dashboard. The data includes the following parameters at 15 minute intervals for each segment:

- Volume
- Speed
- Travel Time

The data is collected by means of loop detectors for each segment of the freeway. Table 4-2 shows the traffic data from the freeway data plotting section of the Dashboard.

Table 4-2. Dashboard Corridor Traffic Plotting Module Snapshot

<table>
<thead>
<tr>
<th>RoadwayID</th>
<th>Segment ID</th>
<th>Slice Time</th>
<th>Avg Speed</th>
<th>Total Volume</th>
<th>Avg Lane Volume</th>
<th>HOV Avg Speed</th>
<th>HOV/Express Avg Lane Volume</th>
<th>GP Avg Speed</th>
<th>GP Avg Lane Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>2</td>
<td>3/16/2012 6:00:00 AM</td>
<td>64</td>
<td>550</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>64</td>
<td>0</td>
</tr>
<tr>
<td>39</td>
<td>2</td>
<td>3/16/2012 6:15:00 AM</td>
<td>65</td>
<td>763</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>85</td>
<td>0</td>
</tr>
<tr>
<td>39</td>
<td>2</td>
<td>3/16/2012 6:30:00 AM</td>
<td>66</td>
<td>1021</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>66</td>
<td>0</td>
</tr>
<tr>
<td>39</td>
<td>2</td>
<td>3/16/2012 6:45:00 AM</td>
<td>66</td>
<td>1238</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>66</td>
<td>0</td>
</tr>
<tr>
<td>39</td>
<td>2</td>
<td>3/16/2012 7:00:00 AM</td>
<td>67</td>
<td>966</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>67</td>
<td>0</td>
</tr>
<tr>
<td>39</td>
<td>2</td>
<td>3/16/2012 7:15:00 AM</td>
<td>67</td>
<td>1236</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>67</td>
<td>0</td>
</tr>
<tr>
<td>39</td>
<td>2</td>
<td>3/16/2012 7:30:00 AM</td>
<td>67</td>
<td>1453</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>67</td>
<td>0</td>
</tr>
<tr>
<td>39</td>
<td>2</td>
<td>3/16/2012 7:45:00 AM</td>
<td>67</td>
<td>1508</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>67</td>
<td>0</td>
</tr>
</tbody>
</table>

To facilitate the computation of incident impacts, the traffic data is collected separately for: non-incident and incident conditions.

Incident Data:

Vehicle speeds, volumes and travel times are collected for each segment for the study period. Then, the speed plots are developed for each segment to determine each incident’s temporal and spatial extents of the impact. The corresponding densities are computed from the speed and volume data.
For each incident, using the formulas described in the methodology, the impacted total volume, impacted average density, and impacted average speed are computed.

**Non-Incident Data:**

The traffic data for the corresponding non-incident scenario over the same spatial and temporal extent and day-of-week is also collected. Traffic data files for non-incident scenario are created by grouping the data according to weekday and overlapping 8-hour time periods. In order to develop the regular traffic conditions without the presence of an incident, 30 data points (for most categories) are collected for each weekday and each time slot, after removal of outliers. The categories are weekdays (MWTR, Fridays, Saturday and Sunday) for overlapping time periods: 5 AM to 1 PM, 9 AM to 5 PM, 1 PM to 9 PM. The average of this is considered the non-incident data for travel speed, volume and travel time for the corresponding day of week and time of day.

Outliers can be detected using the following formulas.

\[ f_s = \text{upper fourth} - \text{lower fourth} \]  \hspace{1cm} (4-1)

\[
\text{Extreme Outlier} = \begin{cases} 
\text{upper fourth} + 3 f_s & \text{OR} \\
\text{lower fourth} - 3 f_s 
\end{cases} \]  \hspace{1cm} (4-2)

where:

- \text{upper fourth} = \text{median of the upper half of the observations when arranged in ascending order}
- \text{lower fourth} = \text{median of the lower half of the observations when arranged in ascending order.}

In order to obtain the true non-incident travel pattern, it is necessary to filter out the days on which construction activities were planned and carried out. The Nevada Department of Transportation was contacted to obtain the database of recorded work zone activities. One of the problems encountered was the lack of electronic documentation of work zone activities. Since most work zone activities were planned during night time, all night time analysis (9 PM to 5 AM) are removed from the study in order to eliminate the risk of the influence of roadway construction work. In addition, the data for planned work zone activities during day time are also removed from
the database. Also, federal holidays are removed from the weekday traffic data since this data would not be representative of the recurrent congestion for weekdays. If federal holidays occurred on weekends, they are retained in the dataset.

### 4.2.3 Data Collection Procedure for Impacts of Incidents

In this section the procedure for computing the impacts of incidents on travel time is employed to the data. As mentioned in the methodology described in Chapter 3, each incident is analyzed separately.

**Step 1. Record incident characteristics.**
Table 4-3 is an example of incident parameters for one incident.

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>TimeStamp</th>
<th>Corridor</th>
<th>Segment Description</th>
<th>Roadway ID</th>
<th>Segment ID</th>
<th>Blocked Lanes</th>
<th>Blockage Description</th>
<th>Block Duration</th>
<th>TowTruckCome TimeStamp</th>
<th>LaneCleared TimeStamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturday</td>
<td>2/4/12</td>
<td>5:53:00 PM</td>
<td>I-15 NB before Flamingo Rd</td>
<td>70</td>
<td>2</td>
<td>2</td>
<td>center lanes</td>
<td>25</td>
<td>6:18:00 PM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Step 2.** The spatial and the temporal extent of the incident are determined

Figure 4-6 shows the speed segment plots for the example incident. Each line in the figure represents the speed profile over time for a single segment. The segments are numbered in ascending order from South to North. The incident took place on segment number 76. From Figure 4-6, the temporal extent is from 5:30 PM to 6:45 PM. The spatial extent is from segment 72 to 76. The corresponding extent in the opposing direction including an additional segment downstream of the incident is used to determine the rubbernecking extent. Table 4-4 shows the same for the sample incident under consideration.
Figure 4-6. Speed-Segment Plot showing Spatial and Temporal extents of Sample Incident

Table 4-4. Sample Incident Parameters

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>TimeStamp</th>
<th>Corridor</th>
<th>Segment Description</th>
<th>Roadway ID</th>
<th>Segment ID</th>
<th>Blocked Lanes</th>
<th>Blockage Description</th>
<th>Block Duration</th>
<th>LaneCleared TimeStamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturday</td>
<td>2/4/12</td>
<td>5:53:00 PM</td>
<td>I-15 NB</td>
<td>Before Flamingo Rd</td>
<td>70</td>
<td>2</td>
<td>2</td>
<td>Center lanes</td>
<td>25</td>
<td>6:18:00 PM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time Affected</th>
<th>Segments Affected (Spatial extent)</th>
<th>Rubbernecking</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 5:30:00 PM</td>
<td>From 76</td>
<td>From 50</td>
</tr>
<tr>
<td>To 6:45:00 PM</td>
<td>To 72</td>
<td>To 53</td>
</tr>
</tbody>
</table>
Step 3. Computation of incident and non-incident impact parameters
Tables 4-5 and 4-6 show examples of spreadsheet calculations for average traffic parameters for incident and non-incident conditions using the formulas from Section 3.3.2 for the sample incident used in the above steps. The process is carried out for rubbernecking direction also.

Step 4. Computation of impacts
The difference between incident and non-incident condition is computed as the impact of each incident. Added to this, are the impacts in the rubbernecking direction as well. Table 4-7 shows the summary of the analysis data for the sample incident.

4.2.4 Fuel Consumption and Vehicle Emissions
Simulation of fuel consumption and emissions can be performed by popular software packages, of which EPA’s Motor Vehicle Emission Simulator (MOVES) is the most widely used in the United States. Song et al. (2009) conducted a study to compare two simulation software, EMFAC and MOVES, in terms of the production of greenhouse gases in Los Angeles County. The paper compared the characteristics of both software and highlighted the fact that the use of speed bins in MOVES made it a superior analysis tool when compared to the use of Speed Correction Factor in EMFAC.

Therefore the MOVES model is used to estimate the vehicle emissions and fuel consumptions for each incident and the corresponding non-incident scenario in this study. A smaller sample size (116 incidents) was used for the MOVES runs due to fact that the simulation process was very time-consuming. The run-time varies depending upon the number of segments and time periods and the processing speed of the computer. For example, for one incident with 2.5 hours’ impact period and 11 segments took around 90 minutes for one run. The following section describes the data used for the estimation of fuel consumption and vehicle emissions using MOVES.
<table>
<thead>
<tr>
<th>SeQ ID</th>
<th>tTime</th>
<th>SeQ ID</th>
<th>tTime</th>
<th>Av Speed</th>
<th>Av TT</th>
<th>Av Volu Time segs</th>
<th>FMS Distance</th>
<th>Density</th>
<th>Lanes</th>
<th>Vol (vphpl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>72</td>
<td>5:30:00 PM</td>
<td>61</td>
<td>0.3678</td>
<td>1116</td>
<td>1</td>
<td>0.3712</td>
<td>14.74</td>
<td>5</td>
<td>893</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>5:45:00 PM</td>
<td>62</td>
<td>0.3579</td>
<td>1131</td>
<td>2</td>
<td>0.3712</td>
<td>14.54</td>
<td>5</td>
<td>905</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>6:00:00 PM</td>
<td>63</td>
<td>0.3551</td>
<td>1021</td>
<td>3</td>
<td>0.3712</td>
<td>13.02</td>
<td>5</td>
<td>817</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>6:15:00 PM</td>
<td>62</td>
<td>0.3572</td>
<td>1081</td>
<td>4</td>
<td>0.3712</td>
<td>13.86</td>
<td>5</td>
<td>865</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>6:30:00 PM</td>
<td>62</td>
<td>0.3572</td>
<td>1097</td>
<td>5</td>
<td>0.3712</td>
<td>14.07</td>
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<td>878</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>6:45:00 PM</td>
<td>63</td>
<td>0.3558</td>
<td>1018</td>
<td>6</td>
<td>0.3712</td>
<td>13.00</td>
<td>5</td>
<td>814</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>5:30:00 PM</td>
<td>59</td>
<td>0.4939</td>
<td>1465</td>
<td>1</td>
<td>0.4817</td>
<td>19.95</td>
<td>5</td>
<td>1,172</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>5:45:00 PM</td>
<td>59</td>
<td>0.4949</td>
<td>1483</td>
<td>2</td>
<td>0.4817</td>
<td>20.24</td>
<td>5</td>
<td>1,186</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>6:00:00 PM</td>
<td>59</td>
<td>0.4915</td>
<td>1378</td>
<td>3</td>
<td>0.4817</td>
<td>18.69</td>
<td>5</td>
<td>1,103</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>6:15:00 PM</td>
<td>59</td>
<td>0.4928</td>
<td>1459</td>
<td>4</td>
<td>0.4817</td>
<td>19.82</td>
<td>5</td>
<td>1,167</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>6:30:00 PM</td>
<td>59</td>
<td>0.4921</td>
<td>1469</td>
<td>5</td>
<td>0.4817</td>
<td>19.92</td>
<td>5</td>
<td>1,175</td>
<td></td>
</tr>
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<td>5</td>
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</tr>
<tr>
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<td>0.2227</td>
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<td>5</td>
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<td>6:15:00 PM</td>
<td>60</td>
<td>0.2247</td>
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</tr>
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<td>0.2245</td>
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<tr>
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<td>0.2691</td>
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<td>0.2510</td>
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<tr>
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<td>57</td>
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<td>0.2510</td>
<td>17.55</td>
<td>5</td>
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<td>0.3851</td>
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<td>7</td>
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<td>7</td>
<td>987</td>
<td></td>
</tr>
<tr>
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<td>66</td>
<td>0.3507</td>
<td>1632</td>
<td>3</td>
<td>0.3851</td>
<td>14.13</td>
<td>7</td>
<td>933</td>
<td></td>
</tr>
<tr>
<td>76</td>
<td>6:15:00 PM</td>
<td>65</td>
<td>0.3566</td>
<td>1710</td>
<td>4</td>
<td>0.3851</td>
<td>15.06</td>
<td>7</td>
<td>977</td>
<td></td>
</tr>
<tr>
<td>76</td>
<td>6:30:00 PM</td>
<td>66</td>
<td>0.3501</td>
<td>1745</td>
<td>5</td>
<td>0.3851</td>
<td>15.11</td>
<td>7</td>
<td>997</td>
<td></td>
</tr>
<tr>
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<td>65</td>
<td>0.3543</td>
<td>1580</td>
<td>6</td>
<td>0.3851</td>
<td>13.83</td>
<td>7</td>
<td>903</td>
<td></td>
</tr>
</tbody>
</table>
Table 4-6. Worksheet with Traffic Data and Impact Travel Time Calculations for Incident Conditions

<table>
<thead>
<tr>
<th>Inc No</th>
<th>ExVHrs</th>
<th>AddTT</th>
<th>ImpTime</th>
<th>ImpSpace</th>
<th>NIDensity</th>
<th>NIVol</th>
<th>NISpd</th>
<th>Weekday</th>
<th>Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>145.41</td>
<td>1.2085</td>
<td>75</td>
<td>1.71</td>
<td>16</td>
<td>961</td>
<td>61</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
About MOVES

MOVES was developed by EPA’s Office of Transportation and Air Quality. It is an open source software written in JAVA and MySQL. MOVES can be used to estimate national, state, county and project level emissions and consumption. MOVES has been designed to aid in estimating vehicle emissions from different types and ranges of vehicles under user defined conditions. It is an improvement over EPA’s previous model MOBILE6, with a feature allowing for analysis on a project level, which fits the requirements for the research at hand.

Data for Emissions and Fuel Consumption Estimation using MOVES

A MOVES run is performed by creating a run specification (RunSpec) file to define the run details such as place, time, vehicle, road type, fuel etc. The RunSpec file is an XML file type and can be edited and executed either manually or with the use of the MOVES GUI. The data required by MOVES for project-level analyses include:

- Traffic data: Speeds and Volumes
- Geometry: Segment Lengths and Grades
- Meteorology: Temperature and Humidity
- Fuel information
- Vehicle fleet/population
- Vehicle age distribution

Traffic data- Speeds and Volumes:

Traffic data for each incident from Dashboard is used as input in MOVES. Speeds and volumes for each segment and time period are provided in the input file for every MOVES run.

Geometry- Segment Lengths and Grades:

The length of each segment is available from the RCT data. The grades of the individual segments are needed in order for MOVES to compute the emission and fuel consumption estimates, since acceleration and deceleration are major contributing factors. Since this information was not readily available from any source, field measurements of elevations are conducted with the help of Global Positioning System (GPS). In this study, Garmin’s eTrex Legend C GPS receiver units are used
for measuring the elevation (Figure 4-7). The unit was set to record GPS data, including elevations, at 3 second intervals. In order to improve data accuracy, five GPS runs were made and for each location the elevation was calculated as the average of the elevations from the five runs.

![Garmin eTrex Legend C handheld GPS unit](www.garmin.com)

Figure 4-7. Garmin eTrex Legend C handheld GPS unit (Source: www.garmin.com)

The formulas used are shown below:

\[
Rise = E_{end} - E_{start} \quad \text{feet}
\]  \hspace{1cm} (4-3)

\[
SegmentGrade = \frac{Rise}{SegmentLength} \times 100\%
\]  \hspace{1cm} (4-4)

Where:

- \(E_{start}\): elevation of the segment start point in feet
- \(E_{end}\): elevation of the segment end point in feet
- \(SegmentLength\): The length of the road segment in feet.

**Meteorology data:**

Another data requirement for MOVES is the temperature and humidity corresponding to the time and location of the facility being modeled. For this study, this data was acquired from the National Oceanic and Atmospheric Administration’s (NOAA) National Climatic Data Center\(^1\), which maintains the data on a website accessible by the general public. Data for the year 2010 for Clark

\(^1\) [http://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=cdo&theme=hourly&layers=00000001&extent=-139.2:12.7:-50.4:57.8&node=gis](http://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=cdo&theme=hourly&layers=00000001&extent=-139.2:12.7:-50.4:57.8&node=gis) - URL
County, Nevada, which is the site of the study, was downloaded in Excel format. The sources of this data are the recordings at McCarran International Airport, Las Vegas. The data from NCDC contains the temperatures and dew points recorded for every hour of the day. From the temperature and dew point, the humidity is computed by first calculating the saturated vapor pressure and actual vapor pressure, as shown below (Humidity Formulas, n.d.):

\[
VP_{Saturated} = 6.11 * 10^{7.5T/(2373+T)}
\]

\[
VP_{Actual} = 6.11 * 10^{7.5D/(2373+D)}
\]

Relative Humidity = \( \frac{VP_{Actual}}{VP_{Saturated}} \)

Where:
- \( T \) = Temperature in degree Celsius
- \( D \) = Dew point in degree Celsius
- \( VP_{Saturated} \) = Saturated Vapor Pressure in Pascal
- \( VP_{Actual} \) = Actual Vapor Pressure in Pascal

**Fuel information**

There are two subsets of information entered under the fuel section: fuel type and fuel formulation. The fuel type specifies the kind of fuel (gasoline, electricity, diesel fuel etc.) used. In this study, diesel and gasoline are used. Fuel formulation is a set of data on the characteristics of a fuel subtype such as its sulfur level, benzene content, olefin content etc. The default data for Clark County from the MOVES database is used for fuel formulation. This data has been collected and compiled from multiple US counties over the years by EPA.

**Vehicle fleet/population:**

The various types of vehicles (called Source Types) and their corresponding codes that can be entered in MOVES are shown in Table 4-8. The distribution of vehicle population on the segment during the time of the run is required by MOVES for every segment.
The distribution of vehicle types for this study is adopted from NDOT vehicle classification report for the years 2010 and 2011 (shown in Table 4-9). The data for 2012 is estimated from this using the growth rate between the previous two years. This data is matched with the MOVES requirements in Table 4-8 according to the standard FHWA axle and vehicle classification, as shown in the last column of Table 4-8. The appropriate AADTs are then obtained to give the percent distribution in Table 4-10. The same process is used for the other two segments Flamingo to US-95 and US-95 to Speedway.

**Vehicle age distribution:**

This input lists the fraction of distribution of the vehicle ages for each segment. MOVES stores a default dataset for the national average age distribution from numerous US counties. Owing to lack of data availability from the local DMV and DOT, the default database is used for this input criterion.

### Table 4-8. MOVES Vehicle Type Classification

<table>
<thead>
<tr>
<th>Code</th>
<th>Vehicle Type</th>
<th>Highway Performance Monitoring System Vehicle Class</th>
<th>Axles</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Motorcycle</td>
<td>Motorcycle</td>
<td>2</td>
</tr>
<tr>
<td>21</td>
<td>Passenger Car</td>
<td>Passenger Car</td>
<td>2</td>
</tr>
<tr>
<td>31</td>
<td>Passenger Truck</td>
<td>Other Two-Axle/Four Tire, Single Unit</td>
<td>2,3</td>
</tr>
<tr>
<td>32</td>
<td>Light Commercial Truck</td>
<td>Other Two-Axle/Four Tire, Single Unit</td>
<td>2,3</td>
</tr>
<tr>
<td>41</td>
<td>Intercity Bus</td>
<td>Bus</td>
<td>2</td>
</tr>
<tr>
<td>42</td>
<td>Transit Bus</td>
<td>Bus</td>
<td>2,3</td>
</tr>
<tr>
<td>43</td>
<td>School Bus</td>
<td>Bus</td>
<td>2</td>
</tr>
<tr>
<td>51</td>
<td>Refuse Truck</td>
<td>Single Unit</td>
<td>2</td>
</tr>
<tr>
<td>52</td>
<td>Single Unit Short-Haul Truck</td>
<td>Single Unit</td>
<td>2</td>
</tr>
<tr>
<td>53</td>
<td>Single Unit Long-Haul Truck</td>
<td>Single Unit</td>
<td>3,4</td>
</tr>
<tr>
<td>54</td>
<td>Motorhome</td>
<td>Single Unit</td>
<td>4</td>
</tr>
<tr>
<td>61</td>
<td>Combination Short-Haul Truck</td>
<td>Combination</td>
<td>5</td>
</tr>
<tr>
<td>62</td>
<td>Combination Long-Haul Truck</td>
<td>Combination</td>
<td>6 or more</td>
</tr>
</tbody>
</table>

2 [http://www fhwa dot gov/policy/ohpi/vehclass htm](http://wwwfhwa dot gov/policy/ohpi/vehclass htm)
Table 4-9. NDOT Vehicle Classification Report, 2011

<table>
<thead>
<tr>
<th>AADT</th>
<th>Avg Wtd AADT</th>
<th>PC-AADT</th>
<th>Light trucks</th>
<th>Heavy Trucks</th>
<th>TruckAADT</th>
<th>Year</th>
</tr>
</thead>
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<tr>
<td>St Rose</td>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>st rose</td>
<td>728</td>
<td>silver</td>
<td>60,000</td>
<td></td>
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<td>silver 5340</td>
<td>blue</td>
<td>104,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>blue 453</td>
<td>i215</td>
<td>139,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>i215 1021</td>
<td>russ</td>
<td>225,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>russ 52 trop</td>
<td>220,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>trop 61 flam</td>
<td>255,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>flam 67 spr.mou</td>
<td>257,000</td>
<td>Falmingo Rd Intch.</td>
<td>257,000</td>
<td>249,330</td>
<td>380</td>
</tr>
<tr>
<td>8</td>
<td>spr.mou 74</td>
<td>sahara</td>
<td>257,000</td>
<td>Sahara Ave</td>
<td>257,000</td>
<td>248,985</td>
</tr>
<tr>
<td>9</td>
<td>Sahara 1210</td>
<td>char</td>
<td>254,000</td>
<td>Sahara Ave</td>
<td>252,500</td>
<td>244,295</td>
</tr>
<tr>
<td>10</td>
<td>char 92 us95</td>
<td>251,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>us95 98</td>
<td>wash</td>
<td>158,000</td>
<td>L.V. Intch.</td>
<td>157,000</td>
<td>149,075</td>
</tr>
<tr>
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<td>wash 424</td>
<td>l.mead</td>
<td>156,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>mead 1230</td>
<td>chey</td>
<td>125,000</td>
<td>Lake Mead Intg</td>
<td>61,400</td>
<td>52,445</td>
</tr>
<tr>
<td>14</td>
<td>chey 387</td>
<td>craig</td>
<td>78,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>craig 378</td>
<td>lamb</td>
<td>38,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>lamb 1451</td>
<td>XX</td>
<td>33,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>XX 843 speed</td>
<td></td>
<td>33,000</td>
<td></td>
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</tbody>
</table>

Table 4-10. Vehicle percent distribution St. Rose-Flamingo, 2011

<table>
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<th>linkID</th>
<th>sourceTypeID</th>
<th>sourceTypeHourFraction</th>
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<tbody>
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<td>1</td>
<td>11</td>
<td>267</td>
</tr>
<tr>
<td>1</td>
<td>21</td>
<td>1,53,997</td>
</tr>
<tr>
<td>1</td>
<td>32</td>
<td>3,026</td>
</tr>
<tr>
<td>1</td>
<td>41</td>
<td>839</td>
</tr>
<tr>
<td>1</td>
<td>52</td>
<td>751</td>
</tr>
<tr>
<td>1</td>
<td>53</td>
<td>4,598</td>
</tr>
<tr>
<td>1</td>
<td>54</td>
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<tr>
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<td>61</td>
<td>362</td>
</tr>
<tr>
<td>1</td>
<td>62</td>
<td>203</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,64,350</td>
</tr>
</tbody>
</table>
4.2.5 Data Preparation for MOVES

All the input data for MOVES are required to be arranged in a specific template and format in order to run and be processed by the software without any errors. The default database structure from MOVES is used to obtain the format for each type of input and the data is rearranged to suit the template as required by MOVES. For example, Table 4-11 shows the input format for the meteorology data arranged in the format specified by MOVES. The month ID, zone ID and hour ID gives the details of incident regarding the month, location (county) and time of the incident along with the temperature and relative humidity.

Table 4-11. Sample MOVES Input Format: Meteorology

<table>
<thead>
<tr>
<th>monthID</th>
<th>zoneID</th>
<th>hourID</th>
<th>temperature</th>
<th>relHumidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>320030</td>
<td>15</td>
<td>62.7</td>
<td>25.3</td>
</tr>
</tbody>
</table>

Creation of Input files

As explained in the data description for MOVES (Section 5.2.3), the input file needs to be in a specific format. Although two separate runs are performed for the incident and non-incident, the input file is the same for both except for traffic parameters, since all the remaining conditions such as geometry and location are the same. The file has two separate sheets for incident and non-incident with their respective traffic data. Figure 4-8 presents a snapshot of the MOVES data entry GUI. The list of steps to enter the input and run MOVES and the detailed procedure can be obtained from the MOVES user manual on the EPA website.

MOVES runs are repeated for incident and non-incident conditions for all the incidents in the sample set. Table 4-12 shows the final database with the excess fuel consumption and vehicle emissions for each incident using the output from MOVES.

---

Figure 4-8. MOVES Data Entry Window
### Table 4-12. Fuel Consumption and Vehicle Emissions: Partial Data

(Excess fuel consumption and vehicle emissions in gallons and grams, respectively)

<table>
<thead>
<tr>
<th>Incident No</th>
<th>CO2 (grams)</th>
<th>CO (grams)</th>
<th>NO (grams)</th>
<th>NOx (grams)</th>
<th>PM10 (grams)</th>
<th>Fuel (grams)</th>
<th>Excess (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>634,192</td>
<td>2,761</td>
<td>603</td>
<td>685</td>
<td>16</td>
<td>64</td>
<td>12,109</td>
</tr>
<tr>
<td>5</td>
<td>786,746</td>
<td>3,348</td>
<td>779</td>
<td>885</td>
<td>18</td>
<td>80</td>
<td>(9,304)</td>
</tr>
<tr>
<td>7</td>
<td>8,395,826</td>
<td>29,921</td>
<td>7,406</td>
<td>8,414</td>
<td>233</td>
<td>841</td>
<td>2,013,917</td>
</tr>
<tr>
<td>8</td>
<td>1,661,540</td>
<td>6,133</td>
<td>1,550</td>
<td>1,762</td>
<td>42</td>
<td>168</td>
<td>101,474</td>
</tr>
<tr>
<td>10</td>
<td>5,862,279</td>
<td>27,385</td>
<td>5,265</td>
<td>5,983</td>
<td>146</td>
<td>585</td>
<td>1,207,296</td>
</tr>
<tr>
<td>14</td>
<td>2,641,294</td>
<td>8,674</td>
<td>2,110</td>
<td>2,420</td>
<td>94</td>
<td>264</td>
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<td>Fuel</td>
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<td>SO2</td>
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CHAPTER 5: DESCRIPTIVE SUMMARY STATISTICS

5.1 Introduction

This chapter presents the descriptive summary statistics of the data for impacts of traffic incidents. Before embarking on the regression and model calibration, various variable summary statistics are generated to evaluate whether or not the distributions and trends between variables are intuitive. However, it should be noted that the histograms and box-plots presented are applicable to the corresponding variables mentioned when used separately and do not show the interaction and influence of the rest of the variables.

5.2 Summary of Descriptive Statistics

5.2.1 Introduction

Except for the additional travel time, spatial and temporal extents, the summary statistics for each of the other impact variables presented here are for the combined primary incident direction and the rubbernecking (i.e., opposite) directions. For example, the excess vehicle-hours of travel is the sum of the excess VHT in the primary direction and the excess VHT in the rubbernecking direction. This was done primarily due to what was observed in the preliminary analysis that there were no significant observed trends between the rubbernecking impacts by themselves and the incident characteristics.

5.2.2 Incident Duration

Figure 5-1 shows the histogram of incident durations for all the incidents in the sample set.
Figure 5-1. Histogram of Incident Clearance Durations (minutes)

(Mean = 29.35; Median = 25.5 minutes)

The distribution is positively skewed as can be expected in the real-world. The average and median durations are 29.35 and 26 minutes, respectively.

Figure 5-2 shows that the average incident duration for two lanes blocked is higher than for one lane, implying, as expected, that two lane incidents are typically more severe than single lane incident resulting in higher incident duration. However it should be noted also that the incident duration for shoulder incidents (zero blocked lanes) are higher than the single blocked travel lane incidents. This may indicate a lower sense of urgency for clearing incidents that do not block travel lanes.
5.2.3 Additional Average Travel Time

This section presents histograms and box-plots of the impact in terms of the additional average travel time over the impacted segment in the primary direction, i.e., same travel direction as the incident location. Figures 5-3 show the histogram of the additional travel time, in minutes/vehicle. The distribution is skewed to the right following the expected trend that typically high-impact incidents are not as frequent as the lower impact incidents. The mean additional travel time is 1.32 minutes per vehicle (median 1.05) in the primary direction. The latter represents the average additional travel time for all the vehicles that are impacted, i.e., those vehicles that are within the temporal and spatial extents of the incident.
Figures 5-3. Histogram: Additional Travel Time per vehicle

(Mean value = 1.32; Median = 1.05 minutes/vehicle)

Figures 5-4 show box-plots of travel time impact for different numbers of blocked lanes. Box-plots show median values (the horizontal lines in the middle of the box) of the response variable, quartiles and range of values. The individual points plotted above or below the lower and upper fences are statistically outliers. Zero blocked lanes means the incident occurred on the shoulder and no travel lanes were blocked. The figures show an expected trend, namely, the more the number of travel lanes blocked the higher the impact in terms of the additional travel time.

Similarly, Figure 5-5 Shows box-plots of the additional travel times as functions of the incident duration. Incident durations are grouped into five categories 1, 2, 3, 4, and 5 corresponding to incident durations of 15 minutes or less, greater than 15 minutes up to 30, greater than 30 minutes up to 45 minutes, greater than 45 minutes up to 60, and finally greater than 60 minutes, respectively. Again the plot show the expected trend, namely, the higher the incident duration, the higher the impact in terms of the additional travel time.
Figure 5-4. Box-plot: Primary Additional Travel Time (in minutes) Vs. Number of Blocked Lanes

Figure 5-5. Box-plot: Average Primary Additional Travel Time (in minutes/vehicle) Vs. Incident Duration
5.2.4 Excess Vehicle-Hours of Travel (VHT)

This section presents histograms and box-plots of the impact in terms of the excess total vehicle-hours of travel for all the impacted vehicles combined. Figure 5-6 shows the histogram of the excess vehicle hours of travel. Again, as expected, the distributions are skewed to the right following the expected trend that typically high-impact incidents are not as frequent as the medium and low impact incidents. The mean impact vehicle-hours of travel is 244.04 per incident (median 134.67).

Figures 5-7 and 5-8 show box-plots of the excess VHT impact for different numbers of blocked lanes and incident durations, respectively. Also, here the trends are as expected, the higher the number of travel lanes blocked, the higher the impact. The same trend is true for the incident duration.

![Histogram of ExVHrs](image)

Figure 5-6. Histogram: Impact VHT

(Mean = 244.04; Median = 134.7 veh-hrs/incident)
Figure 5-7. Box-plot: Excess VHT Vs. Number of Blocked Lanes

Figure 5-8. Box-plot: Impact in VHT vs. Incident Duration
5.2.5 Temporal and Spatial Extents

Figures 5-9 to 5-12 are box-plots of the temporal and spatial extents for different values of the number of blocked lanes and for different incident duration categories, as earlier explained. Again, the trends observed are as expected, the higher the number of blocked travel lanes, the longer will be the length of the temporal and spatial extents. Similar trends are observed with respect to the incident durations.

Figure 5-9. Box-plot: Temporal Impact (in minutes) Vs. Number of Blocked Lanes
Figure 5-10. Box-plot: Temporal Extent (in minutes) vs. Incident Duration

Figure 5-11. Box-plot: Spatial Impact (in miles) Vs. Number of Blocked Lanes
5.2.6 Fuel Consumption

Figures 5-13 to 5-15 show a histogram and box-plots of incident impacts in terms of fuel consumption. Again, the trends are in general are similar to what is observed with the other variables.
Figure 5-13. Histogram: Excess Fuel Consumption in gallons

Figure 5-14. Box-plot: Excess Fuel Consumption (in gallons) Vs. Number of Lanes Blocked
Figure 5-15. Box-plot: Excess fuel consumption (in gallons) Vs. Incident Duration

5.2.7 Vehicle Emissions

Figures 5-16 to 5-27 show histograms and box-plots of incident impacts in terms of fuel consumption. Again, the trends are in general are similar to what is observed with the other variables. The impacts median of the impacts increase as the number of lanes blocked or the incident durations increase.
Figure 5-16. Histogram: Excess CO$_2$ Emissions in Tons

Figure 5-17. Box-plot: Excess CO2 emissions (in Tons) vs. Number of Blocked lanes
Figure 5-18. Box-plot: Excess CO$_2$ emissions (in Tons) vs. Incident Duration

Figure 5-19. Histogram: Excess CO Emissions in Kgs
Figure 5-20. Box-plot: Excess CO emissions (in Kgs) vs. Number of Blocked lanes

Figure 5-21. Box-plot: Excess CO emissions (in Kgs) vs. Incident Duration
Figure 5-22. Histogram: Excess NO\textsubscript{x} Emissions in grams

Figure 5-23. Box-plot: Excess NO\textsubscript{x} emissions (in Grams) vs. Number of Blocked lanes
Figure 5-24. Box-plot: Excess NOx emissions (in Grams) vs. Incident Duration

Figure 5-25. Histogram: Excess PM$_{10}$ Emissions in grams
Figure 5-26. Box-plot: Excess PM$_{10}$ emissions (in Grams) vs. Number of Blocked lanes

Figure 5-27. Box-plot: Excess PM$_{10}$ emissions (in Grams) vs. Incident Duration
5.3 Summary

This chapter presented the descriptive summary statistics to observe the general trends among certain incident characteristics and the impacts. The impacts of incidents in terms of travel time, fuel consumption and vehicle emissions show an increase with increase in incident duration and number of lanes blocked, as can be expected in the real-world. It is to be noted that these summary statistics do not depict the inter-relationship and influence between other predictor variables and are only for understanding the general trends that can be further studied by statistical modeling.
6.1 Introduction
This chapter presents the statistical modeling results for the impacts of incidents. The statistical package used for modeling is R. The models calibrated include the OLS Linear Model, Log-transformed Linear Model, Gamma GLM, Gaussian GLM with Single-Log, and Gaussian GLM with Double-Log. Some response variables have non-positive observations. A constant greater in magnitude than the most negative observed value is added to all the observed values, to make them positive. This step is required for the Gamma and Gaussian GLM models since they can only be used when the response variables are all positive (use of logarithms).

6.2 Description of Response and Predictor Variables
The list of the response and predictor variables used in the analysis of the incident impacts, their description and codes in R are presented in the following tables (Tables 6-1 and 6-2). It is to be noted that in all the models, the number of travel lanes blocked is used as a dummy variable, as denoted by the variables LNSBLK1 and LNSBLK2. Zero travel lanes blocked (i.e., shoulder incident) will have both variables equal to zero. On the other hand if one travel lane is blocked, then LNSBLK1 will have a value of 1, and if two lanes are blocked LNSBLK2 will be the one to take the value 1.

Tables 6-3 and 6-4 show the correlation matrices for the predictor variables for travel time and fuel consumption and vehicle emissions. Though the predictor variables are the same, fuel and emissions have a different sample size from travel time. The highly correlated variables are highlighted by bold text in the correlation matrices. Since the speed for non-incident condition is correlated with density, it is not used in the models (only density and volume are used). As can be seen from the tables, the number of lanes blocked and ratio of lanes blocked are highly correlated, as are incident duration and lane-minutes of blockage.

Statistical models were calibrated for each response variable using the functional forms described in Section 3.3.3. Stepwise regression analysis was used to identify the significant predictor variables for each response variable for each functional form. The statistical parameters $R^2$, AIC, and residual plots were then used to select the most appropriate function form for each response variable.

67
Table 6-1. List of Response Variables

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<th>Variable Name</th>
<th>Explanation</th>
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<td>Additional Travel Time</td>
<td>Excess travel time during the incident in minutes/incident</td>
</tr>
<tr>
<td>ExVHrs</td>
<td>Excess Vehicle Hours</td>
<td>Excess vehicle-hours of travel experienced by all impacted vehicles in veh-hrs</td>
</tr>
<tr>
<td>ImpTime</td>
<td>Temporal extent</td>
<td>Total time of incident impact in minutes</td>
</tr>
<tr>
<td>ImpSpace</td>
<td>Spatial extent</td>
<td>Freeway segment impacted in miles</td>
</tr>
<tr>
<td>NOx</td>
<td>Excess Oxides of Nitrogen</td>
<td>Excess NOx due to incident in grams</td>
</tr>
<tr>
<td>PM10</td>
<td>Excess Particulate Matter &lt;10 microns</td>
<td>Excess PM10 due to incident in grams</td>
</tr>
<tr>
<td>CO2</td>
<td>Excess Carbon di-oxide</td>
<td>Excess CO2 due to incident in Tons</td>
</tr>
<tr>
<td>CO</td>
<td>Excess Carbon monoxide</td>
<td>Excess CO due to incident in Kilograms</td>
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<td>Fuel</td>
<td>Excess Fuel Consumption</td>
<td>Excess Fuel consumption in gallons</td>
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Table 6-2. List of Predictor Variables

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<td>Weekday</td>
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<td>Peak</td>
<td>Incident happened in peak period (Yes = 1, No = 0)</td>
</tr>
<tr>
<td>ClrT</td>
<td>Incident duration</td>
<td>Time taken to clear the incident</td>
</tr>
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<td>1 Lane Blocked</td>
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<td>2 Lanes Blocked</td>
<td>Two travel lanes blocked (Yes = 1, No = 0)</td>
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<td>Lanes minutes of blockage (product of “incident duration” and “number of lanes blocked”)</td>
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<td>Non-incident Density</td>
<td>Density for non-incident condition in vpmpl</td>
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<td>Non-incident Volume</td>
<td>Volume for non-incident condition in vphpl</td>
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<td>Non-incident Speed</td>
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<td>Rubbernecking Non-incident Density</td>
<td>Density for non-incident condition in vpmpl, for Rubbernecking direction</td>
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<tr>
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<td>Rubbernecking Non-incident Volume</td>
<td>Volume for non-incident condition in vphpl, for Rubbernecking direction</td>
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Table 6-3. Correlation Matrix for Predictor Variables for Travel Time

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<td>0.000</td>
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<tr>
<td></td>
<td>0.015</td>
<td>0.041</td>
<td>0.016</td>
<td>-0.123</td>
<td>0.651</td>
<td>0.613</td>
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<td>0.018</td>
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</tr>
<tr>
<td>RNIDensity</td>
<td>0.748</td>
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<td></td>
<td></td>
<td>0.000</td>
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<td>0.000</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>0.558</td>
<td>0.021</td>
<td></td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>RNIVolume</td>
<td>0.755</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.000</td>
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<td>0.000</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>0.342</td>
<td>0.000</td>
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<td>0.369</td>
<td>0.425</td>
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<td>0.001</td>
<td>0.001</td>
<td>0.002</td>
<td>0.000</td>
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</table>

*p-values in parentheses.*
Table 6-4. Correlation Matrix for Predictor Variables for Fuel and Emissions

<table>
<thead>
<tr>
<th></th>
<th>NIDensity</th>
<th>NIVol</th>
<th>NISpd</th>
<th>Weekday</th>
<th>Peak</th>
<th>LnBlkRatio</th>
<th>BlkLnMin</th>
<th>ClrT</th>
<th>LnsBlk</th>
<th>RNIDensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIVol</td>
<td>0.126</td>
<td>0.179</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NISpd</td>
<td>-0.795</td>
<td>0.056</td>
<td>0.550</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekday</td>
<td>0.362</td>
<td>0.142</td>
<td>-0.273</td>
<td>0.000</td>
<td>0.240</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak</td>
<td>0.291</td>
<td>-0.012</td>
<td>-0.459</td>
<td>-0.012</td>
<td>0.000</td>
<td>0.240</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LnBlkRatio</td>
<td>-0.283</td>
<td>-0.136</td>
<td>0.085</td>
<td>0.000</td>
<td>-0.062</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BlkLnMin</td>
<td>-0.243</td>
<td>0.004</td>
<td>0.172</td>
<td>0.000</td>
<td>-0.175</td>
<td>0.626</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ClrT</td>
<td>-0.185</td>
<td>0.009</td>
<td>0.182</td>
<td>0.000</td>
<td>-0.179</td>
<td>0.303</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LnsBlk</td>
<td>-0.233</td>
<td>-0.021</td>
<td>0.052</td>
<td>-0.255</td>
<td>-0.055</td>
<td>0.890</td>
<td>0.652</td>
<td>0.297</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RNIDensity</td>
<td>0.816</td>
<td>0.123</td>
<td>-0.552</td>
<td>0.286</td>
<td>0.101</td>
<td>-0.312</td>
<td>-0.224</td>
<td>-0.120</td>
<td>-0.276</td>
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</tr>
<tr>
<td>RNIVolume</td>
<td>0.779</td>
<td>0.149</td>
<td>-0.491</td>
<td>0.253</td>
<td>0.090</td>
<td>-0.313</td>
<td>-0.248</td>
<td>-0.154</td>
<td>-0.273</td>
<td>0.974</td>
</tr>
</tbody>
</table>
6.3 Model Results

The results are arranged in the same format for all the response variables for analysis. First, is a summary table with the important measures of all the functional forms modeled, followed by the coefficient estimates for the best model selected. The summary table presents the $R^2$ (regular and adjusted, wherever applicable) and AIC for the Full Model (model with all predictor variables) and Nested model (the final model with only the significant predictor variable from stepwise regression). Also presented are the residual and normality plots for the nested models, as well as the plots of Cook’s distances to determine the presence of outliers. The main criteria used for selecting the best model are the residual and normality plots, $R^2$ and AIC and the list of significant and practically useful variables in the final nested model.

6.3.1 Additional Travel Time

The model results for the analysis for additional travel time per incident experienced by the impacted vehicles are shown in Table 6-5. The Gaussian Double-log model has the best fit based on the residual plots, $R^2$ and AIC measures. Also, since Gaussian log-log model has both incident duration and lanes blocked as significant variables, it is preferred over the Gaussian Single-log model with just the lane-minutes of blockage, though they have very close $R^2$ and AIC. The model output with the coefficient estimates for the Gaussian log-log model for additional travel time is presented in Figure 6-1. The final model form selected is the Gaussian log-log function and is presented in Equation 6-1 below.

\[
\text{Additional Travel Time} = \exp \{ -1.01756 + 0.2616 \times \ln(\text{Non-incident Density}) \\
+ 0.1867 \times \ln(\text{Incident duration}) + 0.3042 \times \text{1 lane blocked} + 0.6027 \times \text{2 lanes blocked}\} - 1
\]

(6-1)

The results show that the coefficient estimates are all positive indicating that, as expected, additional travel time increases with increase in each of the predictor variables. For number of lanes blocked, the coefficient for the dummy variable 2 lanes blocked is higher (approximately by a factor of 2) than for the dummy variable 1 lane blocked, indicating that, additional travel times are higher for an incident with 2 lanes blocked when compared to 1 lane blocked.
### Table 6-5. Results for Excess Additional Travel Time per Impacted Vehicle

<table>
<thead>
<tr>
<th>Category</th>
<th>Linear</th>
<th>Transformed Single Log</th>
<th>Gamma</th>
<th>Gaussian (Log)</th>
<th>Gaussian (Log-Log)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$/ Adj-$R^2$ (%)</td>
<td>26.0 / 22.15</td>
<td>24.07 / 20.12</td>
<td>23.87 /</td>
<td>24.07 /</td>
<td>23.34 /</td>
</tr>
<tr>
<td>AIC</td>
<td>652.21</td>
<td>298.23</td>
<td>585.48</td>
<td>298.23</td>
<td>298.17</td>
</tr>
<tr>
<td>Nested Model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$/ Adj-$R^2$ (%)</td>
<td>22.31 / 21.93</td>
<td>19.08 / 18.68</td>
<td>22.60 /</td>
<td>19.08 /</td>
<td>20.96 /</td>
</tr>
<tr>
<td>AIC</td>
<td>644.09</td>
<td>293.16</td>
<td>581.11</td>
<td>293.16</td>
<td>294.37</td>
</tr>
<tr>
<td>Model Fit (P-value) Accept Model p &gt;0.05</td>
<td></td>
<td></td>
<td></td>
<td>0.497733</td>
<td>0.4867339</td>
</tr>
</tbody>
</table>

- **Residual Vs Fitted**

- **Standardized Residuals**

- **Significant Variables**
  - BlkLnMin
  - LNSBLK
  - ClrT
  - lnNIDensity
  - lnClrT
  - LNSBLK
Final Nested Model:

Call:
glm(formula = lnoneplusTT ~ lnNIDensity + lnClrT + LNSBLK, 
    family = gaussian(), data = x)

Deviance Residuals:
Min        1Q    Median        3Q       Max
-1.41450  -0.39787  -0.03462   0.37754   1.03566

Coefficients:

                          Estimate Std. Error t value Pr(>|t|)
(Intercept)                   -1.0176    0.3675    -2.768  0.000301 **
lnNIDensity                   0.2616    0.1053     2.485  0.010689 *
lnClrT                        0.1867    0.0419     4.453 5.08e-05 ***
LNSBLK1                       0.3042    0.1437     2.116  0.031779 *
LNSBLK2                       0.6027    0.1507     4.000 5.86e-05 ***

---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.2412471)
Null deviance: 60.439  on 202  degrees of freedom
Residual deviance: 47.767  on 198  degrees of freedom

AIC: 294.37

Number of Fisher Scoring iterations: 2

AIC:
294.37

R-Sq:
20.96%

Diagnostic Plots:

Figure 6-1. Best Model: Excess Additional Travel Time per Impacted Vehicle
(Model Form: Gaussian log-log GLM)
6.3.2 Excess Vehicle Hours

The model results for excess vehicle hours of the impacted vehicles are shown in Table 6-6. This is followed by the coefficient estimates for the best model and the diagnostic plots in Figure 6-2. The Gaussian Log-Log model clearly shows the best fit when compared to the other models in terms of the residual and normality plots. The $R^2$ and AIC measures are lower than the Single-log GLM. Therefore, the Gaussian Log-Log model is recommended for estimation of excess vehicle hours of impact (Equation 6-2). The significant variables are the incident duration, the number of travel lanes blocked and the non-incident density. All the signs of the coefficients are positive, indicating, as expected, that the higher the values of these variables, the higher the impact vehicle hours. The results also show that the impact for two lanes blocked is higher than that for only one lane blocked.

\[
\text{Excess VHT} = \exp \{ 1.41944 + 0.66726 \times \ln (\text{Non-incident Density}) + 0.35164 \times \ln (\text{Incident duration}) + 0.750316 \times 1 \text{ lane blocked} + 1.05008 \times 2 \text{ lanes blocked} \} - 50 \tag{6-2}
\]
Table 6-6. Results for Excess Vehicle Hours of Travel for Impacted Vehicles

<table>
<thead>
<tr>
<th>Category</th>
<th>Linear</th>
<th>Transformed (Single Log)</th>
<th>Gamma</th>
<th>Gaussian (Log)</th>
<th>Gaussian (Log-Log)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable: Excess Vehicle Hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$ / Adj-$R^2$ (%)</td>
<td>21.39 / 16.42</td>
<td>27.29 / 22.7</td>
<td>13.58</td>
<td>27.29</td>
<td>28.71</td>
</tr>
<tr>
<td>AIC</td>
<td>2857.4</td>
<td>555.85</td>
<td>2679.7</td>
<td>555.85</td>
<td>549.85</td>
</tr>
<tr>
<td>Nested Model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$ / Adj-$R^2$ (%)</td>
<td>13.32 / 12.46</td>
<td>15.88 / 14.18</td>
<td>8.94</td>
<td>14.54</td>
<td>17.79</td>
</tr>
<tr>
<td>AIC</td>
<td>2857.2</td>
<td>569.44</td>
<td>2688.4</td>
<td>568.65</td>
<td>564.79</td>
</tr>
<tr>
<td>Model Fit (P-value)</td>
<td></td>
<td></td>
<td>0.5989</td>
<td>0.4867</td>
<td>0.4866</td>
</tr>
<tr>
<td>Accept Model p &gt;0.05</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual Vs Fitted</td>
<td><img src="image1" alt="Residual vs Fitted" /></td>
<td><img src="image2" alt="Residual vs Fitted" /></td>
<td><img src="image3" alt="Residual vs Fitted" /></td>
<td><img src="image4" alt="Residual vs Fitted" /></td>
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</tr>
<tr>
<td>Standardized Residuals</td>
<td><img src="image6" alt="Normal Q-Q" /></td>
<td><img src="image7" alt="Normal Q-Q" /></td>
<td><img src="image8" alt="Normal Q-Q" /></td>
<td><img src="image9" alt="Normal Q-Q" /></td>
<td><img src="image10" alt="Normal Q-Q" /></td>
</tr>
<tr>
<td>Significant Variables</td>
<td>Non-incident Density, Lane-minutes of Blockage</td>
<td>Non-incident Density No. of Lanes Blocked, Incident duration</td>
<td>Non-incident Density No. of Lanes Blocked, Incident duration</td>
<td>Non-incident Density, Lane-minutes of Blockage</td>
<td>Non-incident Density No. of Lanes Blocked, Incident duration</td>
</tr>
</tbody>
</table>
Final Nested Model:

```r
Call:
glm(formula = lnExVHrsPlus50 ~ lnNIDensity + lnClrT + LNSBLK,
     family = gaussian(), data = x)

Deviance Residuals:
     Min       1Q     Median       3Q      Max
-2.74623 -0.75976  0.05533  0.67780  2.37534

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  1.41944    0.71547  1.984 0.024322 *
lnNIDensity  0.66726    0.20494  3.256 0.000665 **
lnClrT       0.35164    0.08163  4.308 1.3e-05 ***
LNSBLK1      0.70316    0.27978  2.513 0.006380 *
LNSBLK2      1.05008    0.29328  3.580 0.000216 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.9140856)

Null deviance: 220.15  on 202  degrees of freedom
Residual deviance: 180.99  on 198  degrees of freedom
AIC: 564.79
Number of Fisher Scoring iterations: 2

AIC:
564.79

R-Sq: 17.79%

Diagnostic Plots:  

Figure 6-2. Best Model: Excess Vehicle Hours of Travel for Impacted Vehicles
(Model Form: Gaussian log-log GLM)
6.3.3 Temporal Extent

The model calibration results for the analysis for average temporal extent of incidents are shown in Table 6-7. From these results, the final model recommended for the temporal extent of an incident is the Gaussian Single-log model owing to it’s higher $R^2$ and lower AIC than the log-log GLM. Also, the fit for the Single-log model is good in the diagnostic plots. The coefficient estimates for this model are summarized in Figure 6-3. Equation 6-3 presents the calibrated equation for the selected model.

The coefficient estimates are all positive, except non-incident volume, indicating that the temporal extent of incident impact increases with increase in incident duration, lanes blocked and non-incident traffic density. The coefficient for non-incident volume is negative but also very low. This means that for higher volumes, the impacts are lower which is contrary to expectation.

Temporal Extent = $\exp\{3.244 + 0.02074 \times $ Non-incident Density $ + 0.00843 \times $ Incident duration $ + 0.53700 \times $ 1 lane blocked $ + 0.71050 \times $ 2 lanes blocked $\}$

(6-3)
Table 6-7. Results for Temporal Extent

<table>
<thead>
<tr>
<th>Category</th>
<th>Linear</th>
<th>Transformed (Single log)</th>
<th>Gamma</th>
<th>Gaussian (Log)</th>
<th>Gaussian (Log-Log)</th>
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<td>Variable: Impact Time</td>
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<td></td>
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<tr>
<td>Full Model:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$ / Adj-$R^2$ (%)</td>
<td>18.13 / 12.96</td>
<td>21.71 / 16.76</td>
<td>17.98 /</td>
<td>21.7 /</td>
<td>19.87 /</td>
</tr>
<tr>
<td>AIC</td>
<td>2168.4</td>
<td>392.68</td>
<td>2108.7</td>
<td>392.68</td>
<td>395.39</td>
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<td>Nested Model:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$ / Adj-$R^2$ (%)</td>
<td>13.54 / 11.34</td>
<td>16.98 / 14.88</td>
<td>10.86 /</td>
<td>16.98 /</td>
<td>15.65 /</td>
</tr>
<tr>
<td>AIC</td>
<td>2165.5</td>
<td>390.6</td>
<td>2108.8</td>
<td>390.6</td>
<td>393.8</td>
</tr>
<tr>
<td>Model Fit (P-value)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accept Model p &gt;0.05</td>
<td>0.345</td>
<td>0.4866</td>
<td>0.4866</td>
<td>0.4866</td>
<td></td>
</tr>
<tr>
<td>Residual Vs Fitted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standardized Residuals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significant Variables</td>
<td>Non-incident Density, Non-incident Volume, No. of Lanes Blocked, Incident duration</td>
<td>Non-incident Density, Non-incident Volume, No. of Lanes Blocked, Incident duration</td>
<td>Non-incident Density, Non-incident Volume, No. of Lanes Blocked, Incident duration</td>
<td>Non-incident Density, No. of Lanes Blocked, Incident duration</td>
<td>Non-incident Density, No. of Lanes Blocked, Incident duration</td>
</tr>
</tbody>
</table>
Final Nested Model:

Call:
glm(formula = lnImpTime ~ NIDensity + NIVol + ClrT + LNSBLK, 
     family = gaussian(), data = x)

Deviance Residuals:
          Min       1Q   Median       3Q      Max
-1.60338 -0.31559  0.03039  0.43403  1.35017

Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept) 3.244e+00  2.570e-01   12.620 < 1e-16 ***
NIDensity  2.074e-02  8.323e-03    2.492 0.006768 *
NIVol       1.283e-04  4.022e-05   -3.190  > 0.05
ClrT        8.425e-03  2.370e-03    3.555 0.000122 ***
LNSBLK1     5.370e-01  1.823e-01    2.946 0.001802 **
LNSBLK2     7.105e-01  1.901e-01    3.737 0.000122 ***

---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for gaussian family taken to be 0.3856351)

Null deviance: 91.512  on 202 degrees of freedom
Residual deviance: 75.970  on 197 degrees of freedom
AIC: 390.57

Number of Fisher Scoring iterations: 2

AIC:
390.57

R-Sq:
16.98%

Diagnostic Plots:

Figure 6-3. Best Model: Temporal Extent
(Model Form: Gaussian Single-log GLM)
6.3.4 Spatial Extent

The summary of model results is shown in Table 6-8. The model chosen for the average spatial extent of an incident is the Gaussian Single-log model since it has the best fit from the diagnostic plots. Also, it has a higher $R^2$ and lower AIC than the log-log model. The significant variables are also as expected.

The results of the recommended model are shown in Figure 6-4 and Equation 6-4. The coefficient estimates are once again, all positive, except non-incident volume. Therefore, the spatial extent increases with increase in incident duration, lanes blocked and non-incident traffic density.

\[
\text{Spatial Extent} = \exp \{ -0.8622 + 0.035 \times \text{Non-incident Density} + 0.0102 \times \text{Incident duration} \\
+ 0.7286 \times \text{1 lane blocked} + 0.8024 \times \text{2 lanes blocked} \} 
\]  

(6-4)
Table 6-8. Results for Spatial Extent

<table>
<thead>
<tr>
<th>Category</th>
<th>Linear</th>
<th>Transformed (Single Log)</th>
<th>Gamma</th>
<th>Gaussian (Log)</th>
<th>Gaussian (Log-Log)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable: Spatial Extent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AIC</td>
<td>756.86</td>
<td>460.11</td>
<td>680.84</td>
<td>460.11</td>
<td>464.79</td>
</tr>
<tr>
<td>Nested Model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$ / Adj-$R^2$ (%)</td>
<td>16.39 / 15.13</td>
<td>16.85 / 14.74</td>
<td>13.05 /</td>
<td>16.85 /</td>
<td>15.62 /</td>
</tr>
<tr>
<td>AIC</td>
<td>751.91</td>
<td>457.51</td>
<td>681.72</td>
<td>453.23</td>
<td>460.49</td>
</tr>
<tr>
<td>Model Fit (P-value) Accept</td>
<td></td>
<td></td>
<td></td>
<td>0.1743</td>
<td>0.4866</td>
</tr>
<tr>
<td>Model p &gt;0.05</td>
<td></td>
<td></td>
<td></td>
<td>0.4866</td>
<td>0.4866</td>
</tr>
<tr>
<td>Residual Vs Fitted</td>
<td><img src="image1.png" alt="Residual vs Fitted" /></td>
<td><img src="image2.png" alt="Residual vs Fitted" /></td>
<td><img src="image3.png" alt="Residual vs Fitted" /></td>
<td><img src="image4.png" alt="Residual vs Fitted" /></td>
<td><img src="image5.png" alt="Residual vs Fitted" /></td>
</tr>
<tr>
<td>Standardized Residuals</td>
<td><img src="image6.png" alt="Normal QQ" /></td>
<td><img src="image7.png" alt="Normal QQ" /></td>
<td><img src="image8.png" alt="Normal QQ" /></td>
<td><img src="image9.png" alt="Normal QQ" /></td>
<td><img src="image10.png" alt="Normal QQ" /></td>
</tr>
<tr>
<td>Significant Variables</td>
<td>Non-incident Density, Non-incident Volume, Lane-minutes of Blockage</td>
<td>Non-incident Density, Non-incident Volume, No. of Lanes Blocked, Incident duration</td>
<td>Non-incident Density, No. of Lanes Blocked, Incident duration</td>
<td>Non-incident Density, Non-incident Volume, No. of Lanes Blocked, Incident duration</td>
<td>Non-incident Density, No. of Lanes Blocked, Incident duration</td>
</tr>
</tbody>
</table>
Final Nested Model:

call: glm(formula = lnImpSpace ~ NIDensity + NIVol + ClrT + LNSBLK, 
        family = gaussian(), data = x)

Deviance Residuals:

Min       1Q   Median       3Q      Max
-2.4820 -0.3022  0.0864   0.4879   1.6842

Coefficients:

                     Estimate Std. Error t value Pr(>|t|)
(Intercept)       -8.622e-01  3.031e-01  -2.844 0.002456 **
NIDensity          3.501e-02  9.815e-03   3.567 0.000227 ***
NIVol              -1.247e-04  4.743e-05  -2.630 >0.5
ClrT               1.018e-02  2.795e-03   3.643 0.000173 ***
LNSBLK1            7.286e-01  2.149e-01   3.390 0.000424 ***
LNSBLK2            8.024e-01  2.242e-01   3.579 0.000217 ***

---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.536283)

    Null deviance: 127.05  on 202  degrees of freedom
Residual deviance: 105.65  on 197  degrees of freedom
AIC: 457.51
Number of Fisher Scoring iterations: 2

AIC:
453.23

R-Sq:
16.85%

Diagnostic Plots:

Figure 6-4. Best Model: Spatial Extent

(Model Form: Gaussian Single-log GLM)
6.3.5 Excess Fuel Consumption

Table 6-9 presents the comparison of the results for all the models for excess fuel consumption in gallons. The Gaussian Single-log model represents the excess fuel consumption (in gallons) the best as can be seen from the $R^2$ and AIC measures. The model fit is also the best when compared to the rest of the models. The coefficient estimates for the best model are shown in Figure 6-5 and the model form in equation 6-5. The significant variables in the model are lane-minutes of blockage and non-incident traffic density.

Excess Fuel Consumption = $\exp\{3.36649 + 0.010554 \times \text{Lane-Minutes of Blockage} + 0.036113 \times \text{Non-incident Density}\} - 35 \quad (6-5)$

Lane-minutes of blockage is the product of incident duration and number of lanes blocked (for shoulder incidents, lane-minutes of blockage is zero). The model indicates a positive relationship, with the increase in lane-minutes of blockage and non-incident density leading to increased excess fuel consumption.
Table 6-9. Results for Excess Fuel Consumption

<table>
<thead>
<tr>
<th>Category</th>
<th>Linear</th>
<th>Transformed Single Log</th>
<th>Gamma</th>
<th>Gaussian (Log)</th>
<th>Gaussian (Log-Log)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable: Fuel Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Full Model:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$ / Adj-$R^2$ (%)</td>
<td>30.2 / 22.75</td>
<td>28.44 / 20.8</td>
<td>23.54 /</td>
<td>26.77 /</td>
<td>27.52 /</td>
</tr>
<tr>
<td>AIC</td>
<td>1406.05</td>
<td>294.25</td>
<td>1315.2</td>
<td>292.91</td>
<td>293.72</td>
</tr>
<tr>
<td><strong>Nested Model:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$ / Adj-$R^2$ (%)</td>
<td>21.71 / 20.31</td>
<td>16.96 / 15.48</td>
<td>15.33 /</td>
<td>28.44 /</td>
<td>11.77 /</td>
</tr>
<tr>
<td>AIC</td>
<td>1401.3</td>
<td>293.4</td>
<td>1317.7</td>
<td>294.3</td>
<td>300.3</td>
</tr>
<tr>
<td>Model Fit (P-value) Accept Model $p &gt; 0.05$</td>
<td></td>
<td></td>
<td></td>
<td>0.7121</td>
<td>0.4822</td>
</tr>
</tbody>
</table>

Residual Vs Fitted

Standardized Residuals

Significant Variables

- Non-incident Density, Lane-minutes of Blockage
- Non-incident Density, Lane-minutes of Blockage
- Non-incident Density, Lane-minutes of Blockage
- Non-incident Density, Lane-minutes of Blockage
- Non-incident Density, Incident duration
Final Nested Model:

Call: glm(formula = lnFuelPlus35 ~ BlkLnMin + NIDensity, family = gaussian(), data = fe)

Deviance Residuals:
  Min       1Q   Median       3Q      Max
-3.5452  -0.5659  -0.0015   0.5343   1.5915

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 3.366490   0.311134  10.820  < 1e-16 ***
BlkLnMin    0.010554   0.002301   4.586 0.59    0.05 ***
NIDensity   0.036113   0.014858   2.430   0.0084 *

---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.7189439)

Null deviance: 96.967  on 114  degrees of freedom
Residual deviance: 80.522  on 112  degrees of freedom
AIC: 293.37

Number of Fisher Scoring iterations: 2

AIC:
293.37

R-Sq:
16.96%

Diagnostic Plots:

Figure 6-5: Best Model Results Excess Fuel Consumption (gallons)
(Model Form: Gaussian Single-log GLM)
6.3.6 Excess CO\textsubscript{2} Emissions

Table 6-10 gives a summary of the results for excess carbon di-oxide (CO\textsubscript{2}) in metric tons for the different modeling forms. All of the models do not have a very good fit for excess CO\textsubscript{2} emissions (metric tons). Out of them, the Gaussian Single-Log GLM model provides the best fit where the outliers in the normality plots are a little closer to the normality line than the Gaussian log-log or Gamma. R\textsuperscript{2} is higher and AIC is lower for the Gaussian single-log when compared to the log-log.

The coefficient estimates for the recommended model and diagnostics plots are summarized in Figure 6-6. Equation 6-6 is the final form of the selected model. The significant variables in the model are lane-minutes of blockage and non-incident traffic density. The model indicates a positive relationship, with the increase in lane-minutes of blockage and non-incident density leading to increased excess CO\textsubscript{2} emissions due to incidents.

\[
\text{Excess CO}_2 \text{ Emissions} = \exp\{3.38 + 0.00146 \times \text{Non-incident Density} + 0.00050 \times \text{Lane-Minutes of Blockage}\} - 30
\]  

(6-6)
Table 6-10. Results for total Excess CO₂ Emissions

<table>
<thead>
<tr>
<th>Category</th>
<th>Linear</th>
<th>Transformed Single Log</th>
<th>Gamma</th>
<th>Gaussian (Log)</th>
<th>Gaussian (Log-Log)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Variable: CO₂ Scaled to Tons</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Full Model:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$/Adj-$R^2$ (%)</td>
<td>30.26 / 22.81</td>
<td>30.59 / 23.18</td>
<td>30.47 /</td>
<td>30.59 /</td>
<td>27.9 /</td>
</tr>
<tr>
<td>AIC</td>
<td>341.92</td>
<td>-453.40</td>
<td>336.3</td>
<td>-453.4</td>
<td>-451.03</td>
</tr>
<tr>
<td><strong>Nested Model:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$/Adj-$R^2$ (%)</td>
<td>23.61 / 22.24</td>
<td>23.81 / 22.44</td>
<td>23.56 /</td>
<td>23.8 /</td>
<td>17.09 /</td>
</tr>
<tr>
<td>AIC</td>
<td>334.4</td>
<td>-460.7</td>
<td>329.4</td>
<td>-460.7</td>
<td>-451.8</td>
</tr>
<tr>
<td>Model Fit (P-value) Accept</td>
<td></td>
<td>0.5555</td>
<td>0.4822</td>
<td>0.4821</td>
<td></td>
</tr>
<tr>
<td>Model p &gt; 0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual Vs Fitted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standardized Residuals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significant Variables</td>
<td></td>
<td>Non-incident Density, Lane-minutes of Blockage</td>
<td>Non-incident Density, Lane-minutes of Blockage</td>
<td>Non-incident Density, Lane-minutes of Blockage</td>
<td>Non-incident Density, Incident duration, Lane block ratio</td>
</tr>
</tbody>
</table>
Final Nested Model:

Call:
glm(formula = lnCO2TonsPlus30 ~ NIDensity + BlkLnMin, family = gaussian(), data = fe)

Deviance Residuals:
  Min       1Q  Median       3Q      Max
-0.065443 -0.019731 -0.007994  0.010539  0.119018

Coefficients:
            Estimate Std. Error t value  Pr(>|t|)  
(Intercept) 3.383e+00  1.173e-02 288.550   < 2e-16 ***
NIDensity    1.455e-03  5.600e-04   2.598    0.0053   *
BlkLnMin    5.018e-04  8.673e-05   5.786 3.35e-08 ***

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.001021062)

Null deviance: 0.15009  on 114  degrees of freedom
Residual deviance: 0.11436  on 112  degrees of freedom
AIC: -460.68

Number of Fisher Scoring iterations: 2

AIC: -460.68

R-Sq: 23.80%

Diagnostic Plots:

Figure 6-6. Best Model: Excess CO₂ Emissions (Tons)
(Model Form: Gaussian Single-Log GLM)
6.3.7 Excess CO Emissions

Table 6-11 gives a summary of the results for excess carbon monoxide (CO) emissions for the different regression models. The Gaussian Single-Log model clearly has the better fit, $R^2$ and AIC. The original data was scaled to kilograms. The results for the recommended model are presented in Figure 6-7 and equation 6-7.

The significant variables in the model are lane-minutes of blockage and non-incident traffic density. The model indicates a positive relationship, with the increase in lane-minutes of blockage and non-incident density leading to increased excess CO emissions.

Excess CO Emissions = \( \text{Exp} \{0.511946 + 0.039209 \times \text{Non-incident Density} + 0.009008 \times \text{Lane-Minutes of Blockage}\} - 3 \)  \hspace{1cm} (6-7)
Table 6-11. Results for total Excess CO Emissions (Kg)

<table>
<thead>
<tr>
<th>Category</th>
<th>Linear</th>
<th>Transformed Single Log</th>
<th>Gamma</th>
<th>Gaussian (Log)</th>
<th>Gaussian (Log-Log)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable: CO Emissions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Full Model:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2 / \text{Adj-R}^2$ (%)</td>
<td>32.63 / 25.44</td>
<td>36.86 / 30.12</td>
<td>30.47 /</td>
<td>36.86 /</td>
<td>34.89 /</td>
</tr>
<tr>
<td>AIC</td>
<td>662.52</td>
<td>194.75</td>
<td>561.66</td>
<td>194.75</td>
<td>196.3</td>
</tr>
<tr>
<td><strong>Nested Model:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2 / \text{Adj-R}^2$ (%)</td>
<td>26.19 / 24.87</td>
<td>28.52 / 27.24</td>
<td>17.39 /</td>
<td>28.52 /</td>
<td>23.57 /</td>
</tr>
<tr>
<td>AIC</td>
<td>655.0</td>
<td>191.0</td>
<td>568.2</td>
<td>191.0</td>
<td>200.7</td>
</tr>
<tr>
<td>Model Fit (P-value) Accept Model p &gt; 0.05</td>
<td>0.9105</td>
<td>0.4822</td>
<td>0.4821</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Residual Vs Fitted

Standardized Residuals

Significant Variables

Non-incident Density, Lane-minutes of Blockage

Non-incident Density, Lane-minutes of Blockage

Non-incident Density, Lane-minutes of Blockage

Non-incident Density, Incident duration, Lane block ratio
Final Nested Model:

Call:
glm(formula = lnCOKgPlus3 ~ NIDensity + BlkLnMin, 
family = gaussian(), data = fe)

Deviance Residuals:
Min       1Q   Median       3Q      Max
-1.26781 -0.36017 -0.07009   0.32182   1.26871

Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.5101946   0.199389   2.568   0.0058 *
NIDensity     0.039209   0.009522   4.118 3.68e-05 ***
BlkLnMin      0.009008   0.001475   6.108 0.75e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.2952593)

Null deviance: 46.262  on 114  degrees of freedom
Residual deviance: 33.069  on 112  degrees of freedom
AIC: 191.03
Number of Fisher Scoring iterations: 2

AIC: 191.03

R-Sq: 28.52%

Diagnostic Plots:

Figure 6-7. Best Model: Excess CO Emissions (Kgs)

(Model Form: Gaussian Single-log GLM)
6.3.8 Excess NOx Emissions

Table 6-12 gives a summary of results for excess NOx emissions for the different regression models. Based on these results, the Gaussian Single-log and log-log model have the best fit among all models. Of this, the Gaussian Single-log has the lower AIC and higher $R^2$ and is therefore, recommended. The final model results are shown in Figure 6-8 and equation 6-8.

The significant variables in the model are lane-minutes of blockage and non-incident traffic density, similar to the previous two models. An increase in either of the two variables produces an increase in excess NOx emissions due to incidents.

Excess NOx Emissions = $\exp \{5.03591 + 0.038019 \times \text{Non-incident Density}$

$+ 0.012057 \times \text{Lane-Minutes of Blockage} \} - 250$  \hspace{1cm} (6-8)
Table 6-12. Results for total Excess NO\textsubscript{x} Emissions (grams)

<table>
<thead>
<tr>
<th>Category</th>
<th>Linear</th>
<th>Transformed Single Log</th>
<th>Gamma</th>
<th>Gaussian (Log)</th>
<th>Gaussian (Log-Log)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Variable: NO\textsubscript{x} Emissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Full Model:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R\textsuperscript{2} / Adj-R\textsuperscript{2} (%)</td>
<td>39.02 / 31.51</td>
<td>35.23 / 28.21</td>
<td>38.88 /</td>
<td>35.22 /</td>
<td>34.15 /</td>
</tr>
<tr>
<td>AIC</td>
<td>1783.9</td>
<td>266.3</td>
<td>1691.7</td>
<td>266.3</td>
<td>266.2</td>
</tr>
<tr>
<td><strong>Nested Model:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R\textsuperscript{2} / Adj-R\textsuperscript{2} (%)</td>
<td>28.83 / 27.56</td>
<td>25.0 / 23.66</td>
<td>29.06 /</td>
<td>25.0 /</td>
<td>19.50 /</td>
</tr>
<tr>
<td>AIC</td>
<td>1783.7</td>
<td>265.1</td>
<td>1693.9</td>
<td>265.1</td>
<td>275.3</td>
</tr>
<tr>
<td>Model Fit (P-value) Accept Model p &gt;0.05</td>
<td></td>
<td></td>
<td></td>
<td>0.7713</td>
<td>0.5089</td>
</tr>
</tbody>
</table>

Residual Vs Fitted

Standardized Residuals

Significant Variables

- Non-incident Density, Lane-minutes of Blockage
- Non-incident Density, Lane-minutes of Blockage
- Non-incident Density, Lane-minutes of Blockage
- Non-incident Density, Incident duration, Lane block ratio
Final Nested Model:
Call: glm(formula = lnNOxPlus250 ~ NIDensity + BlkLnMin, family = gaussian(), data = fe)

Deviance Residuals:
Min       1Q   Median       3Q      Max
-2.7968 -0.4239 -0.0944   0.4826   1.4785

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 5.035910   0.275194 18.299  < 1e-16 ***
NIDensity   0.038019   0.013142  2.893  0.00230 **
BlkLnMin    0.012057   0.002036  5.923 1.77e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.5624454)

Null deviance: 83.992  on 114  degrees of freedom
Residual deviance: 62.994  on 112  degrees of freedom
AIC: 265.14

Number of Fisher Scoring iterations: 2

AIC:
265.14

R-Sq:
25.0%

Diagnostic Plots:

Figure 6-8. Best Model: Excess NOx Emissions (grams)
(Model Form: Gaussian Single-log GLM)
6.3.9 Excess PM$_{10}$ Emissions

Table 6-13 gives a summary of the results for PM$_{10}$ emissions for the different regression models. Gaussian Single-log and log-log GLMs have the best fit. Both of these have R$^2$ and AIC that is almost equal.

The log-log model has no representation of the number of lanes blocked which is a very important incident characteristic for practical purposes. Therefore, Gaussian Single-log model is selected for recommendation for excess PM$_{10}$ emission owing to the variable lane-minutes of blockage in it. The model results are summarized in Figure 6-9 and equation 6-9.

Excess PM$_{10}$ Emissions = $\text{Exp} \{ 3.399096 + 0.293358 \times \text{Weekday} + 0.008231 \times \text{Lane-Minutes of Blockage} \} - 30 \quad (6-9)$

The calibrated model has two significant variables, lane-minutes of blockage and a dummy variable indicating if the incident day happened on a weekday or weekend. Both of these variables have positive coefficients. If an incident happened on a weekday, the impact on the excess PM$_{10}$ emissions is more than on a weekend.
Table 6-13. Results for total Excess PM$_{10}$ Emissions (grams)

<table>
<thead>
<tr>
<th>Category</th>
<th>Linear</th>
<th>Transformed Single Log</th>
<th>Gamma</th>
<th>Gaussian (Log)</th>
<th>Gaussian (Log-Log)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variable: PM$_{10}$ Emissions</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Full Model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R$^2$ / Adj-R$^2$ (%)</td>
<td>28.63 / 22.52</td>
<td>27.71 / 21.51</td>
<td>25.92 /</td>
<td>27.70 /</td>
<td>29.56 /</td>
</tr>
<tr>
<td>AIC</td>
<td>1163.4</td>
<td>210.6</td>
<td>1110.2</td>
<td>210.6</td>
<td>209.65</td>
</tr>
<tr>
<td>Nested Model:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R$^2$ / Adj-R$^2$ (%)</td>
<td>21.31 / 19.9</td>
<td>20.16 / 18.74</td>
<td>13.31 /</td>
<td>20.16 /</td>
<td>19.53 /</td>
</tr>
<tr>
<td>AIC</td>
<td>1160.7</td>
<td>208.1</td>
<td>1113.0</td>
<td>208.1</td>
<td>209.0</td>
</tr>
<tr>
<td>Model Fit (P-value)</td>
<td>Accept Model p &gt;0.05</td>
<td>0.6885</td>
<td>0.4822</td>
<td>0.4822</td>
<td></td>
</tr>
<tr>
<td>Residual Vs Fitted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standardized Residuals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significant Variables</td>
<td>Non-incident Density, Lane-minutes of Blockage</td>
<td>Non-incident Density, Lane-minutes of Blockage</td>
<td>Non-incident Density, Lane-minutes of Blockage</td>
<td>Non-incident Density, Lane-minutes of Blockage</td>
<td>Non-incident Density, Incident duration</td>
</tr>
</tbody>
</table>
Final Nested Model:

```
Call:
glm(formula = lnPM10Plus30 ~ Weekday + BlkLnMin,     
     family = gaussian(), data = fe)

Deviance Residuals:
  Min        1Q  Median        3Q       Max
-2.93732 -0.33493 -0.06319  0.30781  1.27335

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  3.39910    0.14230   23.89 < 2e-16 ***
    Weekday   0.29336    0.13376    2.19 0.0015 *
    BlkLnMin  0.00823    0.00158    5.21 4.34e-07 ***

---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.3423557)

    Null deviance: 48.027  on 114  degrees of freedom
  Residual deviance: 38.344  on 112  degrees of freedom

AIC: 208.05

Number of Fisher Scoring iterations: 2
```

AIC: 208.05

R-Sq: 20.16%

Diagnostic Plots:

```
Figure 6-9. Best Model: Excess PM$_{10}$ Emissions (grams)

(Model Form: Gaussian Single-log GLM)
```
6.4 Summary

All the models for incident impacts have positive coefficient estimates indicating that the impacts of incidents (travel time, fuel consumption and vehicle emissions) increase with the increase in incident characteristics. This follows the logic that an incident of bigger magnitude (more number of lanes blocked and more incident duration experienced) will cause more impacts than an incident with lower incident duration and number of lanes blocked. The interpretation and marginal impacts of these models are discussed in Chapter 7.
7.1 Introduction
This chapter describes the interpretation of the models selected for analysis of the marginal impacts of incident characteristics on the response variables. Marginal impact measures the effect on the response variable with a change in one of the predictor variables. Elasticity is defined as the rate of change in a dependent variable with a percent change in a predictor variable. This chapter describes the derivation of the effect of the predictor variable on the original response variable, after the addition of the constant for the Gaussian Single-log and Gaussian Double-log GLMs.

7.2 Derivation of Elasticity for Gaussian Single-Log GLM
In general, the elasticity of a dependent variable $Y$ with respect to predictor variable $X_j$ is given as

$$
\varepsilon_j = \frac{dY}{dX_j} \left( \frac{X_j}{Y} \right)
$$

This means that the value of $Y$ changes by $\varepsilon_j$% for a 1% change in the value of $X_j$. For the Gaussian single-log model used in this study, the functional form of the model is

$$
\ln(Y + A) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p
$$

(7-1)

Where $A$ is the constant used to make LHS positive. Taking exponentiation on both sides,

$$
Y + A = e^{\beta_0 + \beta_j X_j}
$$

$$
Y = e^{\beta_0 + \beta_j X_j} - A
$$

Differentiating,

$$
\frac{dY}{dX_j} = \beta_j e^{\beta_0 + \beta_j X_j} = \beta_j (Y + A)
$$

Therefore,

$$
\varepsilon_j = \frac{dY}{dX_j} \left( \frac{X_j}{Y} \right) = \beta_j (Y + A) \left( \frac{X_j}{Y} \right) = \beta_j X_j \left( 1 + \frac{A}{Y} \right)
$$

(7-2)
For a dummy variable that takes the value of 0 or 1, the derivation for rate of change of $Y$ with in $X_j$ from 0 to 1 is as follows:

$$R_j = \frac{\Delta Y}{Y} = \frac{Y_1 - Y_0}{Y_0} = \frac{(e^{\beta_0 + \beta_j} - A) - (e^{\beta_0} - A)}{(e^{\beta_0} - A)}$$

This simplifies to

$$R_j = \left(1 + \frac{A}{Y_0}\right)(e^{\beta_j} - 1)$$

(7-3)

i.e., If the dummy variable changes from 0 to 1, the change in $Y_0$ is by 100$R_j\%$.

### 7.3 Derivation of Elasticity for Gaussian Log-Log GLM

The functional form for the Gaussian log-log model in this study is given by the following equation:

$$\ln(A + Y) = \beta_0 + \beta_1 \ln(X_1) + \beta_2 \ln(X_2) + \ldots + \beta_p(X_p)$$

(7-4)

Where $A$ is the positive constant added to the dependent variable $Y$ to make sure the LHS of the equation is always positive and there are no errors when taking logs. Taking the exponentiation on both sides,

$$Y + A = e^{\beta_0 + \beta_j \ln(X_j)}$$

$$Y = e^{\beta_0 + \beta_j \ln(X_j)} - A$$

Differentiating,

$$\frac{dY}{dX_j} = \frac{\beta_j}{X_j} e^{\beta_0 + \beta_j \ln(X_j)} = \frac{\beta_j}{X_j} (Y + A)$$

Therefore

$$e_j = \frac{\beta_j}{X_j} (Y + A) \times \frac{X_j}{Y} = \beta_j \left(1 + \frac{A}{Y}\right)$$

(7-5)

For a dummy variable, the derivation is the same as the previous section (Equation 7-3) since the log ($X_j$) in the log-log model only applies to the continuous variables.
7.4 Quantification of Impacts

This section presents calculations for the average and marginal impacts of incident for a given incident scenario. The example below shows the calculations for excess vehicle-hours of travel for an incident blocking one travel lane, lasting 30 minutes with a corresponding non-incident density of 18 vpmpl, the last two parameters being about the average values for the incidents used in this study. Equation 6-2 is used for computing the average impact while the elasticity equation 7-5 is used for estimating the marginal impacts for a 1% change in the incident duration and for a 1 minute change in incident duration. Using equation 6-2,

\[
\text{Excess VHT} = \exp\{1.41944 + 0.66726 \times \ln(\text{Non-incident density}) + 0.35164 \times \ln(\text{Incident duration}) + 0.750316 \times 1 \text{ lane blocked} + 1.05008 \times 2 \text{ lanes blocked}\} - 50
\]

Substituting for the following values: Incident duration = 30 minutes; Non-incident density = 18 vpmpl; 1 lane blocked = 1; and 2 lane blocked = 0.

Then

\[
\begin{align*}
\text{Excess VHT} &= \exp\{1.41944 + 0.66726 \times \ln(18) + 0.35164 \times \ln(30) + 0.750316 \times 1 \\
&\quad + 1.05008 \times 0\} - 50 \\
&= 149.2 \text{ veh-hrs}
\end{align*}
\]

This 149.2 vehicle-hours is the average excess vehicle-hours of travel for an incident of average duration and non-incident density.

Using elasticity equation 7-5,

\[
\varepsilon_j = \beta_j \times \left(1 + \frac{A}{Y}\right) = 0.35164 \times \left(1 + \frac{50}{149.2}\right) = 0.4695
\]

This means that for each 1% change in incident duration, there is a 0.4695% change in the excess VHT. In absolute values, a 1% change in the incident duration results in,

\[
\text{Actual change} = (0.4695/100) \times 149.2 = 0.70 \text{ veh-hrs}
\]
This analysis can be extended to calculate the change in excess VHT for a 1 minute change in the incident duration. A 1 minute change in incident duration from the 30 minutes is equivalent to \((1/30)\% = 3.33\%\) change. Using the elasticity for excess VHT computed above, this will result in \(0.4695 \times 3.33\% = 1.57\%\) change in the excess VHT, which translates to \(149.2 \times 1.57\% = 2.335\) excess VHT.

These calculations are repeated for all the impact variables using appropriate calibrated models and elasticity equations and for 1 and 2 blocked travel lanes. The results are summarized in Tables 7-1 and 7-2.

Table 7-1. Calculated impacts corresponding to average incident conditions

<table>
<thead>
<tr>
<th>Impact Variable</th>
<th>Units</th>
<th>Excess</th>
<th>Excess</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1 lane)</td>
<td>(2 lanes)</td>
<td></td>
</tr>
<tr>
<td>Excess VHT</td>
<td>Veh-hours</td>
<td>149.20</td>
<td>218.84</td>
</tr>
<tr>
<td>Excess Fuel Consumption</td>
<td>Gallons</td>
<td>41.45</td>
<td>69.91</td>
</tr>
<tr>
<td>Excess CO(_2) Emissions</td>
<td>Kgs</td>
<td>613</td>
<td>1,076</td>
</tr>
<tr>
<td>Excess CO Emissions</td>
<td>Kgs</td>
<td>1.45</td>
<td>2.82</td>
</tr>
<tr>
<td>Excess NO(_x) Emissions</td>
<td>Grams</td>
<td>189.60</td>
<td>381.22</td>
</tr>
<tr>
<td>Excess PM(_{10}) Emissions</td>
<td>Grams</td>
<td>21.39</td>
<td>35.78</td>
</tr>
</tbody>
</table>

\(^1\)Applicable for the following incident conditions:
Incident duration = 30 minutes; Non-incident density = 18 vpmpl

Table 7-2. Marginal Impacts for a 1 minute change in incident duration

<table>
<thead>
<tr>
<th>Impact Variable</th>
<th>Units</th>
<th>Marginal</th>
<th>Marginal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1 lane)</td>
<td>(2 lanes)</td>
<td></td>
</tr>
<tr>
<td>Excess VHT</td>
<td>Veh-hours</td>
<td>2.33</td>
<td>3.15</td>
</tr>
<tr>
<td>Excess Fuel Consumption</td>
<td>Gallons</td>
<td>0.80</td>
<td>2.21</td>
</tr>
<tr>
<td>Excess CO(_2) Emissions</td>
<td>Kgs</td>
<td>15.30</td>
<td>31.10</td>
</tr>
<tr>
<td>Excess CO Emissions</td>
<td>Kgs</td>
<td>0.040</td>
<td>0.105</td>
</tr>
<tr>
<td>Excess NO(_x) Emissions</td>
<td>Grams</td>
<td>5.30</td>
<td>15.23</td>
</tr>
<tr>
<td>Excess PM(_{10}) Emissions</td>
<td>Grams</td>
<td>0.423</td>
<td>1.083</td>
</tr>
</tbody>
</table>

\(^2\)Applicable for the following incident conditions:
Incident duration = 30 minutes; Non-incident density = 18 vpmpl
7.5 Project application example

Using the results from Table 7-2 above, one can evaluate a scenario where, for example, an economic analysis has to be conducted to evaluate the economic feasibility of an incident management project that is designed, for example, to reduce the average incident duration from, for example the current 30 minutes to 25 minutes, a reduction in 5 minutes. The resulting reductions or “savings” in impacts will be as summarized in Table 7-3. The values in this table are calculated using the elasticity equations, similar to those obtained for Table 7-2. However, it should be noted that elasticity equations are only applicable for “small” changes in the predictor variable. SO for big changes in the values of the predictor variables, the original calibrated equations may have to be used to calculate the corresponding changes in the impacts.

### Table 7-3. Reduction in Impacts for a 5 minute reduction in average incident duration

<table>
<thead>
<tr>
<th>Impact Variable</th>
<th>Units</th>
<th>Marginal (1 lane)</th>
<th>Marginal (2 lanes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess VHT</td>
<td>Veh-hours</td>
<td>11.65</td>
<td>15.75</td>
</tr>
<tr>
<td>Excess Fuel Consumption</td>
<td>Gallons</td>
<td>4.00</td>
<td>11.05</td>
</tr>
<tr>
<td>Excess CO₂ Emissions</td>
<td>Kgs</td>
<td>76.50</td>
<td>155.5</td>
</tr>
<tr>
<td>Excess CO Emissions</td>
<td>Kgs</td>
<td>0.200</td>
<td>0.525</td>
</tr>
<tr>
<td>Excess NOₓ Emissions</td>
<td>Grams</td>
<td>26.50</td>
<td>76.15</td>
</tr>
<tr>
<td>Excess PM₁₀ Emissions</td>
<td>Grams</td>
<td>2.12</td>
<td>5.42</td>
</tr>
</tbody>
</table>

3Appliable for the following incident conditions: Average incident duration reduced from 30 to 25 minutes; Non-incident density = 18 vpmpl

7.6 Elasticity and Marginal Impact Plots

Impact and elasticity analysis done in the previous section is repeated for different values of the incident duration and the results plotted. The resulting plots show how the elasticity changes as the incident duration is increased or decreased. Figures 7-1 to 7-12 show these plots for each of the impact variables.
Figure 7-1. Elasticity of Excess VHT as a function of Incident Duration

Figure 7-2. Percent Change in Excess VHT for unit change in Incident Duration
Figure 7-3. Elasticity for Lane-Minutes of Blockage in Excess Fuel Consumption

Figure 7-4. Percent Change in Excess Fuel Consumption for unit change in Lane-Minutes of Blockage
Figure 7-5. Elasticity for Lane-Minutes of Blockage in Excess CO$_2$ Emissions

Figure 7-6. Percent Change in Excess CO$_2$ Emissions for unit change in Lane-Minutes of Blockage
Figure 7-7. Elasticity of Excess CO Emissions with respect to incident duration

Figure 7-8. Percent Change in Excess CO Emissions for 1 minute change in incident duration
Figure 7-9. Elasticity of Excess NO\textsubscript{x} Emissions with respect to incident duration

Figure 7-10. Percent Change in Excess NO\textsubscript{x} Emissions for 1 minute change in incident duration
Figure 7-11. Elasticity for Excess PM10 emissions with respect to Incident Duration

Figure 7-12. Percent Change in Excess PM10 Emissions for 1 minute change in incident duration
7.7 Summary

This chapter presents the analysis of the marginal impacts for the calibrated for impacts. These marginal impacts are presented in a form that can be used by agencies to evaluate the cost-effectiveness of an incident management strategy that reduces the incident duration by a certain number of minutes.
CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Concluding Remarks

In this study, statistical models for the impact of freeway incidents on vehicle travel time, fuel consumption and emissions are calibrated. The impacts are quantified by excess travel time measures, fuel consumption and vehicle emissions produced due to the incident. Also included in the analysis are impacts due to rubbernecking in opposite travel direction of the incident direction. Separate regression models are calibrated for each impact. The I-15 freeway from St. Rose Parkway to Speedway Boulevard in Metropolitan Las Vegas, Nevada, is selected for the study. Archived field data from RTC’s Dashboard is used to calibrate the statistical models. The incident database for I-15 for a twelve-month period between March 2011 and March 2012 is used for analysis.

Models are calibrated for (i) excess travel time per vehicle (ii) excess vehicle-hours of travel (iii) excess fuel consumption and (iv) excess vehicle emissions (CO₂, CO, NOₓ and PM₁₀) for all vehicles over the spatial and temporal extent of incidents. The full set of predictor variables used included incident duration, number of lanes blocked, lane-minutes of blockage (product of incident duration and number of travel lanes blocked), location of blocked lanes, ratio of lanes blocked, peak/off-peak period, day-of-week (weekday versus weekend), traffic volume, speed and density for non-incident conditions over the corresponding spatial and temporal extents of incidents.

The statistical model results indicate, as expected, that the most significant predictor variables are the incident duration, number of lanes blocked and the non-incident traffic density. In certain models, the incident duration and lanes blocked were replaced by the product of the two, namely, the lane-minutes of blockage. The resulting functional forms are the Gaussian Single-Log and Double-log GLMs. Use of the models is demonstrated in Chapter 7 by showing examples of using the equations to compute the impact of an average incident. Such analysis can be used for planning purposes and for evaluation of the overall performance of a freeway network. The economic feasibility of any strategies designed to improve safety and reduce such incidents can be performed using these models. Furthermore, elasticity analysis is used to demonstrate use of the models for estimating marginal impacts of incidents for small changes in the values of the incident
characteristics, such as the incident duration and number of blocked lanes. This kind of analysis is used to quantify the reduction in impacts due to incremental changes in incident characteristics, such as reduction in incident duration due to new incident management strategies. In such cases, one can perform a benefit-cost analysis for a proposed incident management project and evaluate its economic feasibility.

8.2 Recommendation for Future Research

Some of the limitations of the current study and suggestions for future work in this topic are discussed in this section.

The first recommendation for future research related to this study is in the data collection effort. This study uses data collected every 15 minutes. Using a shorter data collection interval can improve the accuracy of the calibrated models.

Second, among the challenges encountered in the course of collecting and processing data for this study, the biggest issue is related to the accuracy of the incident data, especially the incident durations and duration of travel lane blockages especially when multiple travel lanes are affected. In these cases, this study has assumed that the start and end of blockage occur at the same time for all the blocked lanes. We know this is not always the case, as occasionally, the lanes may be cleared at different times. This lack of detail results in some overestimation of the blockage. However, the researchers are aware that, since the beginning of 2013, FAST has started keeping snapshot images of the incident scenes for most incidents. These images have the potential to provide more detail information related to the sequence and timing of lane blockages and incident durations during incidents. More accurate models can be calibrated using this more detailed data.

The third recommendation is the need for more detailed work-zone database to ensure that their influence is not included in the analysis. In this study, the researchers are forced to exclude all night-time analysis as work-zone activities are typically scheduled after 9 PM, and due to unavailability of accurate work-zone data that would have helped in isolating impacts due to work-zones.

Fourth, since secondary incidents occur as a result of primary incidents, this study adds the impact of a secondary incident to the primary incident. But the characteristics of the secondary incident itself are not included in the model. Future studies can address this issue by including the characteristics of the secondary incident in the analysis.
Finally, for rubbernecking direction, the inclusion of parameters like median type, geometric location, incident location, and weather and pavement conditions is recommended, since they are not addressed in this study.

REFERENCES


Skabardonis, Alexander; Petty, Karl F.; Noeimi, Hisham; Rydzewski, Daniel; and Varaiya, Pravin (1996) I-880 Field Experiment: Data-base Development and Incident Delay Estimation Procedures. Transportation Research Record No. 1554, p.204-212


