Studying the impacts of primary incidents on freeways to identify secondary incidents

Rohit Reddy Saddi
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STUDYING THE IMPACTS OF PRIMARY INCIDENTS ON FREEWAYS TO IDENTIFY SECONDARY INCIDENTS

by

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Bachelor of Technology
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ABSTRACT

Studying the Impacts of Primary Incidents on Freeways to Identify Secondary Incidents

by

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Freeway incidents are associated with different impacts such as traffic congestion, delays, fuel consumption, secondary incidents etc. Secondary incidents are caused due to primary incidents and require the same personnel who are already engaged. This thesis studies various impacts caused by primary incident in space and time occurring on the freeways and these results are applied to identify secondary incidents. Three types of impacts are identified and proposed in this study. Dynamic nature of queue length in the direction of accident is studied. Dynamic nature of congestion in the opposite direction of the freeway till the accident is cleared is also studied. Dynamic nature of movement of distraction point on the opposite side of the freeway as the queue gets cleared in accident direction is studied. Finally, simulations are carried out by using Las Vegas freeway traffic volumes to show the effect of these impacts in Las Vegas region. The simulation results are applied to real time data to identify secondary incidents.
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# TABLE OF CONTENTS

ABSTRACT ....................................................................................................................... iii

ACKNOWLEDGEMENTS ............................................................................................... iv

LIST OF FIGURES .......................................................................................................... vii

LIST OF TABLES ........................................................................................................... viii

CHAPTER 1 INTRODUCTION ........................................................................................ 1
   Research Goal .............................................................................................................. 1
   Literature Survey ........................................................................................................ 2
   Incident Management .................................................................................................. 2
   Secondary Incidents ................................................................................................... 2
   Rubber Necking ...................................................................................................... 3
   Outline of the Thesis .................................................................................................... 3

CHAPTER 2 INCIDENT MANAGEMENT...................................................................... 5
   Literature Review on Incident Management ............................................................ 5
   Roles and Responsibilities in Incident Management ............................................. 9
   Federal Highway Administration (FHWA) ............................................................ 9
   Federal Emergency Management Administration (FEMA) ................................ 10
   Department of Safety - Nevada Highway Patrol (NHP) ....................................... 10
   Nevada Department of Transportation District 1 .................................................. 10
   Nevada Department of Transportation - HQ ........................................................ 11
   Freeway Service Patrol ......................................................................................... 11
   Nevada Department of Transportation Communications Department ............. 11
   Las Vegas Metropolitan Police Department (MPD) ............................................. 11
   Law Enforcement .................................................................................................. 12
   North Las Vegas Police Department (NLVPD) .................................................... 12
   Clark County Environmental and Risk Management ......................................... 12
   Clark County Coroner’s Office ............................................................................. 12
   Clark County Fire Department (CCFD) .............................................................. 13
   Clark County Public Works (Maintenance) ......................................................... 13
   Clark County Regional Flood Control District (RFCD) ...................................... 13
   City of Henderson Police Department (CHPD) .................................................... 13
   RTC Freeway Arterial Transportation System (FAST) .......................................... 14
   Citizens Area Transit (CAT) ............................................................................... 14
   American Medical Response (AMR) Ambulance ................................................. 14
   Towing and Recovery Operators ......................................................................... 15
   HazMat Contractors .............................................................................................. 15

CHAPTER 3 SECONDARY INCIDENTS ...................................................................... 16
   Introduction .............................................................................................................. 16
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature review</td>
<td>19</td>
</tr>
<tr>
<td>Rubbernecking</td>
<td>23</td>
</tr>
<tr>
<td>CHAPTER 4 IDENTIFYING SECONDARY INCIDENTS</td>
<td>24</td>
</tr>
<tr>
<td>Case Study Video</td>
<td>24</td>
</tr>
<tr>
<td>Identified impacts of primary incidents</td>
<td>30</td>
</tr>
<tr>
<td>Data</td>
<td>31</td>
</tr>
<tr>
<td>Methodology</td>
<td>33</td>
</tr>
<tr>
<td>CHAPTER 5 SIMULATIONS</td>
<td>37</td>
</tr>
<tr>
<td>Representing the incident location in terms of miles</td>
<td>37</td>
</tr>
<tr>
<td>Peak moderate and low traffic volume estimation</td>
<td>37</td>
</tr>
<tr>
<td>Least mean square estimation method</td>
<td>41</td>
</tr>
<tr>
<td>Vissim</td>
<td>48</td>
</tr>
<tr>
<td>Simulation of the secondary congestion in the same direction as the primary incident</td>
<td>50</td>
</tr>
<tr>
<td>Simulation of the effect of the primary incident on the opposing traffic</td>
<td>53</td>
</tr>
<tr>
<td>Simulation of the dynamic nature of Congestion in the opposite direction of the freeway</td>
<td>59</td>
</tr>
<tr>
<td>Matlab code</td>
<td>61</td>
</tr>
<tr>
<td>Results</td>
<td>61</td>
</tr>
<tr>
<td>CONCLUSIONS</td>
<td>63</td>
</tr>
<tr>
<td>APPENDIX - DESIGNER GUIDE</td>
<td>65</td>
</tr>
<tr>
<td>APPENDIX - DEVELOPER GUIDE</td>
<td>67</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>92</td>
</tr>
<tr>
<td>VITA</td>
<td>95</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

3.1 Impact of incident without and with incident management........................................ 9
3.1 Increase in overall time and queue due to secondary incidents .............................. 17
3.2 Secondary incidents on both sides of a freeway...................................................... 18
3.3 Static Thresholds .................................................................................................... 21
3.4 Incident Progression curve .................................................................................... 22
4.1 The intersection of Linwood area 405 and interstate 5 in north Seattle .................. 25
4.2 An accident takes occurred at 2:55 pm ............................................................... 26
4.3 Queue length formed in the opposite direction due to rubbernecking ............... 27
4.4 12 miles of back up at 3:20 PM ......................................................................... 28
4.5 Progression of the queue after the incident is clearance ..................................... 29
4.6 Data sample ........................................................................................................... 31
4.7 Sample AADT data ............................................................................................... 32
5.1 Section of freeway showing the location of incident ............................................ 49
5.2 Section of freeway used in visism .......................................................................... 50
5.3 Queue formed in the direction of primary incident .............................................. 51
5.4 Congestion on the other side of the freeway for less traffic ............................. 54
5.5 Congestion on the other side of the freeway for moderate traffic ..................... 57
5.6 Congestion on the other side of the freeway for heavy traffic ............................ 57
5.7 Dynamic movement of Congestion point on the other side of the freeway ....... 59
A.1 Modified data ......................................................................................................... 65
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>I-15 cross street locations in terms of miles</td>
<td>38</td>
</tr>
<tr>
<td>5.2</td>
<td>US-95 cross street locations in terms of miles</td>
<td>41</td>
</tr>
<tr>
<td>5.3</td>
<td>I-215 cross street locations in terms of miles</td>
<td>42</td>
</tr>
<tr>
<td>5.4</td>
<td>Estimation of peak traffic volume</td>
<td>44</td>
</tr>
<tr>
<td>5.5</td>
<td>Estimation of moderate traffic volume</td>
<td>46</td>
</tr>
<tr>
<td>5.6</td>
<td>Estimation of low traffic volume</td>
<td>47</td>
</tr>
<tr>
<td>5.7</td>
<td>Tracking the locations of front and back of the queue in incident direction</td>
<td>52</td>
</tr>
<tr>
<td>5.8</td>
<td>Congestion on the other side of the freeway for less traffic</td>
<td>55</td>
</tr>
<tr>
<td>5.9</td>
<td>Congestion on the other side of the freeway for moderate traffic</td>
<td>56</td>
</tr>
<tr>
<td>5.10</td>
<td>Congestion on the other side of the freeway for heavy traffic</td>
<td>58</td>
</tr>
<tr>
<td>5.11</td>
<td>Dynamic movement of Congestion point on the other side of the freeway</td>
<td>60</td>
</tr>
<tr>
<td>5.12</td>
<td>Rate of queue increased and queue decreased for different scenarios</td>
<td>62</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

1.1 Research Goal

In United States, traffic crashes are among the top 10 factors causing fatalities. The statistics of traffic crashes are expected to increase from 9th position in 1999 to 3rd position by 2020. This statistics exclude property damages, medical costs and effect of the crashes in the form of travel delay, fuel consumption etc [1].

In 2002, Texas transportation institute reported that traffic in 75 urban areas experienced 52% to 58% of delay due to crashes and vehicle breakdowns costing $67.5 billion to U.S. in 2000. The greatest impact of traffic incidents concerns the safety of incident responders and the motoring public relative to the occurrence of secondary crashes at or upstream of the primary incident site. These incidents need to be cleared as quickly as possible. Otherwise, they pose severe capacity restrictions, congestion, delays and the potential for secondary incidents. The temporary closing of one freeway travel lane reduces the available capacity of single-direction, two-lane and three-lane freeways by 65% and 51%, respectively (Gordon et al. 1996) [20]

According to car accident statistics, every 12 minutes in the U.S. a person will die in a vehicle crash, which is the leading cause of death for Americans of 35 years of age and younger.

The above statistics clearly shows that these incidents are to be addressed very quickly and effectively. The delay in clearing incidents not only costs U.S in terms of economy, but also it poses a severe risk to the life of commuters. A bad incident handling builds up the queue for miles and even takes several hours to clear the incident. These
kind of situations apparently increases the potential for secondary incidents. An extensive research is taking place on studying and designing the effective incident management programs anon effectively using the total available capacity of freeways. A thorough study on secondary incidents can greatly help in designing efficient incident management programs. This not only helps in reducing number of incidents but also reduces the fatalities, fuel consumption, travel delay etc.

This thesis mainly identifies the various impacts caused by primary incidents on freeways. The effects of these impacts are studied thoroughly using simulations. Further, these impacts are applied to the real time data to identify secondary incidents. This thesis also discusses the importance of incident management program and its advantages in different states.

1.2 Literature Survey

1.2.1 Incident Management

Incident management is an extremely important technique employed to operate or bring back the capacity of the freeway to its normal and safe operating condition as early as possible after an incident. It is the process of coordinating the resources of different partner agencies and private sector companies to detect respond to and clear the traffic incident as quickly as possible. Successful incident management program requires a strong interagency involvement and coordination between transportation agencies, emergency response agencies, private sector interests and the media.

1.2.2 Secondary Incidents

Secondary incidents are caused due to the occurrence of primary incident. These incidents require the same personnel engaged in primary incidents which in turn increase
the delay, congestion, clearance time etc. This effect further raises the potential for more number of secondary incidents. Recent studies indicate that more than 20% of incidents are secondary in nature. Thus, in-depth analyses on the occurrence of secondary incidents can help to reduce the number of incidents as well as to design an effective incident management programs. Researchers have used the static spatial and temporal parameters to identify secondary incidents. However, the previous research excluded the effect of rubbernecking due to primary incidents.

1.2.3 Rubber Necking

Rubbernecking is the phenomenon of drivers slowing down their vehicles to look at the events such as car accidents, police stops etc. Rubbernecking causes traffic jams in both directions of the freeway resulting in increased delay, clearance time and secondary incidents. According to the California Department of Highways, rubbernecking on the highways is one of the chief causes of traffic delays and the study of traffic accidents conducted by the Virginia DMV and VCU reveals that rubbernecking is responsible for 16% of all distraction-related accidents.

1.3 Outline of the Thesis

This thesis is divided into the following chapters.

1. Chapter 1 presents the research goal and literature survey conducted for this thesis
2. Chapter 2 presents the study of incident management program. This chapter provides the importance, advantages, benefits and costs of incident management. This chapter discusses the roles and responsibilities of different agencies involved in Incident management program.
3. Chapter 3 presents the study of secondary incidents. This chapter studies on how the previous researchers defined secondary incidents and their approach in identifying them.

4. Chapter 4 analyzes a video used as a case study to identify the impacts caused by primary incidents and their influence on secondary incidents. This chapter also proposes the impacts caused by primary incidents and presents a methodology to identify secondary incidents.

5. Chapter 5 presents the numerical simulations using least mean square estimation method and VISISIM to find the boundary conditions required to identify secondary incidents as stated in chapter 4. Simulations are performed using matlab to calculate the queue length and to identify secondary incidents.
CHAPTER 2
INCIDENT MANAGEMENT

2.1 Literature Review on Incident Management

“Incident” refers to an event that degrades safety and impedes the normal traffic flow. An event may include disabled vehicles, crashes, maintenance activities, adverse weather conditions and debris on the roadway. Incident-related traffic congestion including secondary impacts highly affects public safety, the environment and the local economy. It is estimated that congestion will cost the U.S. public $75 billion in lost productivity and 8.4 billion gallons of wasted fuel in the year 2005 [6]. Traffic incident related delays are estimated to cause 50 to 60 percent of the total congestion delay. These incidents pose a severe risk on the occurrence of secondary incidents, which accounts to 20% of all the incidents and 18% of total deaths [4]. These secondary incidents further increases the traveler delay, increased fuel consumption, reduced air quality and when combined with work zones, delays and costs to the construction project.

Nevada is the seventh largest state in size and 35th in population with more than 2.4 million people residing in the state. From 1997 to 2006, Nevada’s population increased 47.8% while its annual total collisions increased by 5.5%. Although, Nevada’s crash rate per 100 million vehicle miles has been reduced in the past 10 years, it still ranks among the top ten states with the highest crash rates in the nation. During the year 2006, there was a total of 62,225 traffic collisions out of which 40,962 were property damage only (PDO), 20,876 were injury related and 387 were fatal. This reflects 1.3% increase in overall collisions from the total 61,339 recorded in 2005. It is estimated
that the total economic loss resulting from traffic collisions in Nevada for the year 2006 is $1.873 billion [16].

Further, Nevada’s population is expected to grow to 2.8 million people by 2010 and vehicle travel is expected to increase to 35 billion miles of travel annually - an increase of 80 percent by 2010. The State of Nevada continues to lead the nation in population growth and the increase is projected to be approximately 60 percent between now and 2030. The rapid increase in population and the present statistics of crash rates indicates that proper management tools are needed to manage incidents and improve the safety of commuters on freeways. A particular management plan should be developed and implemented with the consensus of different participating agencies to clear the incidents as quickly as possible. Incident Management is such a program developed nationwide to effectively address the incidents.

“Incident management” is a coordinated approach in managing incidents that occur on the highway. It is the systematic, planned and coordinated use of human, institutional, mechanical and technical resources to reduce the duration and impact of incidents, improve the safety of motorists, crash victims and incident responders. Effectively using these resources can also increase the operating efficiency, safety, and mobility of the highway [15].

Incident management involves a series of activities, which can be carried out by personnel from a variety of response agencies and organizations. The program includes (a) Incident Detection: A process by which an incident is brought to the attention of traffic incident management team. This can happen in many ways such as

• Calls from motorist
• CCTV cameras
• Motorist aid telephones or call boxes
• Police patrols
• Automatic vehicle identification (AVI) combined with detection software
• Electronic traffic measuring devices (e.g., video imaging, loop or radar detectors) and algorithms that detect traffic abnormalities
• Department of transportation or public works crews reporting via two-way radio
• Aerial surveillance
• Traffic reporting services
• Fleet vehicles (transit and trucking)
• Roaming service patrols

(b) Incident Verification: It is the process of confirming that the incident has taken place, getting the exact location and obtaining as many primary details as possible about the incident. Usually arrival of the first responder on the scene confirms the incident. This can also be accomplished in many ways such as
• CCTV cameras
• Dispatch field units (police or service patrols) to the incident site
• Communications with aircraft operated by the police, the media, or an information service provider
• Calls from multiple motorists

(c) Motorist Information: This involves creating the awareness about the incident to the public which helps them to take the alternate routes. The following technologies are used to disseminate the information
• Commercial radio broadcasts

• Variable message signs (VMS)

• Highway advisory radio (HAR)

• Telephone information systems

• In-vehicle or personal data assistant information or route guidance systems

• Commercial and public television traffic reports

• Internet/on-line services

(d) Response: This is the most important activity in the incident management process which involves dispatching appropriate equipment, personnel, and activating the required communication links. Effective response involves preparedness by a number of agencies (i.e., planned cooperatively) involved in the traffic incident management team.

(e) Site Management: This involves managing resources on site in real-time following proper pre-determined protocols and policies. Site management ensures the safety of responders, incident victims and the oncoming traffic. It usually involves following a formal command system known as incident command system (ICS). The ICS sets the guidelines for planned and organized approach to be followed by emergency responders at the incident.

(f) Traffic Management: This involves coming up with alternate routes, dispatching personnel at the incident for traffic management if necessary and then managing traffic control devices to alleviate congestion on site.

(g) Clearance Incident: clearance is the process of removing wreckage, debris, or any other element that disrupts the normal flow of traffic, or forces lane closures, and restoring the roadway capacity to its pre-incident condition.
2.2 Roles and Responsibilities in Incident Management

For effective Incident management, each and every agency participating in an Incident clearance should have specific roles and responsibilities. The existing roles and responsibilities of the emergency responders in the Las Vegas region are discussed below

2.2.1 Federal Highway Administration (FHWA)

It sets the standards, publishes best practices for traffic incident management, provides planning guides and training options for partners involved in traffic incident management and helps in operating Highways.
2.2.2 Federal Emergency Management Administration (FEMA)

It mainly manages national emergencies and hazards. It provide federal response and recovery efforts, trains first responders, manages the National Flood Insurance police, and the U.S. Fire Administration.

2.2.3 Department of Safety - Nevada Highway Patrol (NHP)

NHP is the primary first responding agency for incident management. It serves as incident command in most incidents on the freeway/highway for the Las Vegas region with the responsibility of managing the incident, traffic diversions, clearance of the roadway and investigation of crash scenes on state highways and interstate freeways. NHP serves as the Public Safety Answering Point (PSAP) taking 911 calls and when other 911 calls are contacted by travelers regarding freeway/highway incidents, those calls are forwarded to NHP. It interacts with all emergency agencies including coroners office in case of fatalities and public information media regarding incidents and maintains dispatcher availability 24/7 from NHP-RTC FAST. NHP posts DMS messages and monitors CCTV video feeds when FAST employees are not available (24/7 access is not available yet but is underway). Computer Aided Dispatch (CAD) system is used to locate and manage incident information (this system cannot currently communicate directly with other agencies systems). It primarily uses cell phones and radios for communication. NHP maintains secure information system inaccessible by others and provides security oversight of NHP RTC FAST TMC agencies.

2.2.4 Nevada Department of Transportation District 1

NDOT provides staff assistants in assisting traffic control, cleaning up debris, managing HAZMAT cleanup and repairing the roadway. It works with NHP and other
regional emergency responders to provide 511 information about the region traffic status for the statewide 511 system feature. It uses newly provided hand held radios, cell phones and emails for communication. It operates and maintains four Highway Advisory Radios (HAR) in Southern Nevada and manages FAST agreement and provides funding for TMC Facilities Management position.

2.2.5 Nevada Department of Transportation - HQ

It manages and funds Freeway Service Patrol (FSP) to assist drivers and NHP with traffic incident management. It manages 511 Statewide and Statewide Traffic Incident Management Team efforts. It reviews and makes policy on Traffic Incident Management, quick clearance and legislative recommendations for TIM development in the state of Nevada.

2.2.6 Freeway Service Patrol

FSP offers roadside assistance that is in need. It assists in safety of drivers and individuals at incident scenes. It provides assistance to NHP with traffic control to prevent secondary incidents, rapid removal of vehicles and debris from travel lanes and paved shoulder.

2.2.7 Nevada Department of Transportation Communications Department

It manages and oversees State NDOT radio systems, the statewide communications committee and helps in integration of communications systems whenever requested.

2.2.8 Las Vegas Metropolitan Police Department (MPD)

MPD serves as the Public Safety Answering Point (PSAP) taking 911 calls and when other 911 is contacted by travelers regarding freeway/highway incidents, those calls are forwarded to NHP. Along with NHP, MPD manages the incident on County roads, traffic.
diversions, and clearance of the roadway. It informs all emergency agencies and public information media regarding incidents via individual agency dispatchers. It owns and operates 700 MHz radio system.

2.2.9 Law Enforcement

It conducts traffic incident management on arterial and local (and some freeway) systems.

2.2.10 North Las Vegas Police Department (NLVPD)

It serves as the Public Safety Answering Point (PSAP) taking 911 calls and when other 911 is contacted by travelers regarding freeway/highway incidents, those calls are forwarded to NHP. Operates AIMS system for traffic incident management on corridors in the NLVPD area and manages traffic for the Las Vegas Speedway. NLVPD communicates with other first response agencies via individual dispatchers and attends traffic incident management calls.

2.2.11 Clark County Environmental and Risk Management

It works with NHP during incidents that involve large commercial vehicles. It manages HAZMAT contract for clearance of HAZMAT spills and/or removal of commercial vehicles from the Clark County right-of-way.

2.2.12 Clark County Coroner’s Office

Along with NHP, Coroner’s office participates in clearing and investigating the incidents involving deaths. It assists in leadership efforts at the TIM to develop policies and support regional quick clearance agreement.
2.2.13 Clark County Office of Emergency Management and Homeland Security

It participates in emergency management, focusing on policy decision making, identification of resource capabilities (ingress / egress), public information and rumor control. It has no direct operational responsibilities in incident management and clearance.

2.2.14 Clark County Fire Department (CCFD)

CCFD is the primary emergency responder or incident command agency for fire incidents, hazardous material spills, rescue, and extraction of trapped crash victims for Clark County. It helps the incident management team in clearing incidents and contacts towing agency to tow the vehicle once the situation is stabilized. It keeps the data of the past incidents.

2.2.15 Clark County Public Works (Maintenance)

This department is responsible for managing incidents and clearance of incidents on CC-215. It closes and reopens roadways for use whenever necessary and generates a report of the incident. Clark County traffic signals and roadside equipment maintenance on County right-of-way are taken care by this department.

2.2.16 Clark County Regional Flood Control District (RFCD)

It acts only when flash flood events occur. It collects data and shares with other agencies such as FAST for analysis. FAST video feeds may be helpful for surveillance and verification of water on roadway instances.

2.2.17 City of Henderson Police Department (CHPD)

As NLVPD and MPD, it serves as the Public Safety Answering Point (PSAP) taking 911 calls for Henderson. It plays a important role in reporting incidents, preserving
evidence, reopening roadways for use and generating report of the incident in Henderson area, Communicates with MPD and NLVPD using a dedicated radio channel and CAD technology to aid communication with NLVPD.

2.2.18 RTC Freeway Arterial Transportation System (FAST)

It operates RTC FAST center and performs traffic monitoring and control via CCTV’s, detectors, DMS, ramp meters and FMS software. RTC has full access to most signal controllers in the Valley which can alter the signal timings accordingly during incident clearance. Communicates face-to-face during incidents with NHP, RTC FAST TMC and helps NHP and NDOT in incident management by providing data and tools to identify incidents and assisting with remote monitoring of the incident scene. It provides trailblazer signs to utilize and assist diverted motorists with detour route information during incidents. It supports the Traffic Incident Management (TIM) Coalition by working with NDOT to support meetings and provide video taping of incidents in a quality that can be utilized for debriefing incidents at the TIM.

2.2.19 Citizens Area Transit (CAT)

It has contracts for vehicle removal, debris clean up and Hazmat clean up for a crash involving a transit vehicle. It determines transit bus detour routes. It provides incident information with law enforcement agencies and Office of Homeland Security on request.

2.2.20 American Medical Response (AMR) Ambulance

AMR is the primary source of providing first-aid at the incident site and thereafter transporting patient from incident to hospital. This service will be requested by 911 or NHP.
2.2.21 Towing and Recovery Operators

Removes wrecked or disabled vehicles and debris from incident scenes. They work with TIM partners to accomplish regional quick clearance agreement.

2.2.22 HazMat Contractors

It helps TIM in cleaning and disposing the toxic or hazardous materials at the incident site. Based on the incident severity, the TIM coalition group set the timing goals in clearing the incident as follows

- 30 minutes for fender-benders.
- 60 minutes for injury crashes.
- 90 minutes for accidents involving fatalities.
CHAPTER 3
SECONDARY INCIDENTS

3.1 Introduction

Traffic incidents are non-recurring events that not only reduces the roadway capacity but may also lead to more number of incidents, known as ‘secondary incidents’. Secondary incidents can increase congestion, incident duration, fuel consumption and emissions. The temporary obstruction of zero, one or two lanes of a freeway reduce the available capacity by 17, 63 and 77 percent, respectively (Gordon et al.1996) [20]. Furthermore, the effect of rubbernecking reduces the freeway capacity by 50% [5] [10] [13] [14]. Consequently, incidents have serious implications due to the resulting traffic congestion causing approximately 33 to 60 percent of all delays costing the US billions of Dollars every year [3] [19]. Moreover, overheating of engines and truncated spacing between vehicles due to incident related congestions accounts for 60 percent of total freeway congestion [25], these factors significantly increases the likelihood of secondary incidents deteriorating congestion, clearance time, and safety [3] [10][26]. The likelihood of a secondary crash increases by 2.8 percent for each minute of delay in clearing the primary incident. Causes include the dramatic change in traffic conditions, including the rapid spreading of queue length, and the substantial drop in traffic speed, as well as rubbernecking [7]. Secondary crashes due to congestion resulting from a previous crash are estimated to represent 20 percent of all crashes. The below figure shows the increase in clearance and recovery times due to the occurrence of secondary incidents.
Figure 3.1: Increase in overall time and queue due to secondary incidents

Secondary Incidents are partially or fully related to the occurrence of an earlier event [22]; they are a significant source of freeway incidents composing approximately 20 percent of total number of nonrecurring events [19] [28]. Therefore, it is vital to clearly define secondary incidents for research purposes as well as incident management operations in order to reduce any involved risks. However, due to the lack of real time data regarding secondary incidents, the relationship between primary crash characteristics and the occurrence of secondary incidents are not defined accurately. The previous research has been defining secondary incidents by allocating localized static or dynamic thresholds limited in time and space. Furthermore, previous studies have only considered congestion in the same direction of the primary incident. Whereas, rubbernecking is
responsible for 16 percent of all distraction related incidents [5]. Figure 3.3 shows the possible secondary incidents on both sides of the freeway Primary Incident

![Diagram of secondary incidents on both sides of a freeway](image)

Figure 3.2: Secondary incidents on both sides of a freeway

A wide variety of factors such as visibility, time of the day, clearance time, drivers tolerance towards congestion etc are involved in occurrence of secondary incidents. Therefore, localizing thresholds in space and time will not cover all events that are possibly secondary, which leads to erroneous statistics that may be used in studies, investigations, and incident management processes. In order to minimize secondary incidents, an extensive research is to be carried out to study the impacts created by the primary incidents and their influence on the occurrence of secondary incidents. A standard measure for identifying them must be developed taking into consideration the dynamic movement of the front and back of the queue even after the incident clearance. Furthermore, congestion that forms in the opposite direction of the incident must be
studied as well. In this study, a dynamic progression curve that is unique to every event and its parameters, such as severity of incident, volume, and clearance times is proposed.

3.2 Literature Review

An in-depth analysis is needed to accurately define a secondary incident. Moreover, the factors contributing the occurrence of secondary incidents are to be studied extensively. A proper research in this field can greatly reduce the number of secondary incidents which in-turn benefits the incident management programs. Review on secondary incidents will certainly help in designing an effective method to identify the number of secondary incidents and the factors contributing to the occurrence of these incidents. Unfortunately, research in this topic is very limited. This is mainly due to the lack of documenting incident data and related traffic data with sufficient fields that are necessary for secondary incident analysis [28].

Due to the lack of proper data, researchers are constantly enhancing the definition of secondary incidents. Various methods have been proposed to identify secondary incidents based on the availability of data in their respective areas.

The first and foremost definition of secondary incidents is presented by Raub in [22]. He presented a static temporal and spatial analysis of incidents to identify secondary incidents. According to his study, secondary incidents are those occurring less than 15 minutes plus clearance time after an initial incident and within a distance of 1 mile. He found that more than 15% of the incidents are secondary in nature. Similar study was conducted by Karlaftis in [12]. He assumed the same thresholds as Raub to identify the magnitude of secondary incidents in Indiana State. His findings also resulted in 15% of secondary incidents. However, these two studies cited in [12] [22] have excluded the
secondary incidents in the opposite direction of the flow associated with a primary incident that leads to the inaccurate results.

Therefore, the author in [17] enhanced the definition of secondary incidents by considering that any incident occurred upstream from the location of incident in either direction within the queue as secondary. This study also uses static temporal and spatial analysis along with the loop detector data to estimate the queue length required to identify the secondary incidents. His finding shows that secondary incidents are less frequent in Los Angeles than suggested in previous studies. Furthermore, Hirunyanitiwattanain [9] studied the characteristics of secondary incidents compared to the primary incidents. A proportionality test is used to find the differences between the pairs of secondary incidents and the difference between secondary incidents and primary incidents according to the collision type, crash severity time of the day, road classification, rural and urban areas etc.

However, the interdependency between the duration of primary incidents and the occurrence of secondary incidents is explored in [13]. Higher duration of primary incidents increase the chances of secondary incidents which in turn increase the duration of primary incidents [13]. Nonetheless, definition of secondary incidents in [13] are those that take place in the same roadway segment of the primary averaging one mile as well as same duration if no lanes are blocked and plus 15 minutes if lanes are blocked. Static thresholds are also used in [13] [17] and [28] limiting time and space to clearance time and a two mile long queue in the same direction.

The close observation on the review so far reveals that, only temporal and spatial parameters are varying greatly based on the local traffic conditions of the area being
studied, but the methodology used to identify secondary incidents remains same. The static threshold that has been used so far in defining secondary incidents is depicted in Figure 3.3. It suggests that the incidents that fall within the rectangle formed by the threshold, which is determined by the maximum clearance length and clearance time, are defined as secondary. For instance, incidents A and C in Figure 1. However, this method is erroneous since clearly not all incidents that take place within these boundaries are secondary such as incident C. Furthermore, not all secondary incidents are covered such as incident B which occurs within the queue caused by the primary incident.

Sun, in [24] addresses the flaw in using static thresholds when defining secondary incidents and proposes a dynamic progression curve representing the queue formed due
to an incident. Depicted in Figure 3.4 is the progression curve of the queue length as a result of incident related congestion. The queue progression curve demonstrates dynamic nature of queue formation as incident time progresses. The peak of the curve is the incident’s clearance time and the maximum queue length. In [24], 5514 freeway incidents were analyzed, and it was found that incidents identified by static and dynamic thresholds can vary up to 30 percent.

![Incident Progression curve](image)

Figure 3.4: Incident Progression curve

Even though, Sun [24] addressed the flaw in using static thresholds, he hasn’t considered the overall impacts caused by primary incidents on freeways. For instance, progression curve of rubbernecking effect was not addressed. Therefore, a complete
study on the impacts of primary incidents on freeways and their influence on the occurrence of secondary incidents is desired.

### 3.3 Rubbernecking

The incident in one direction of the freeway influences the traffic in the opposite direction. Slowdown of vehicles or reduction in the capacity of the freeway due to the incident in opposite direction is termed as 'Rubbernecking'. Rubbernecking is caused due to the driver’s curiosity to look at the incident and the impact of rubbernecking depends on the severity and the type of an incident. Rubbernecking cause’s traffic jams, capacity reduction, increased delay making the whole scenario much worse on either side of the freeways.

In 2004, according to the National Highway Traffic Safety Administration’s Fatality Analysis Reporting System, over 40,000 Americans died because of traffic crashes. The largest study on crashes involving distracted drivers has found that rubbernecking causes more accidents.

Car accident statistics indicate 98 percent of reported accidents involve a single distracted driver. Rubbernecking was the highest percentage of single distractions, followed by driver fatigue, looking at scenery or landmarks, passenger or child distractions, adjusting the radio or other music form, and cell phone use.

A study by the Virginia Commonwealth University shows that rubbernecking caused by all outside distractions accounts for 35% out of which 16% are incident related.
CHAPTER 4
IDENTIFYING SECONDARY INCIDENTS

In this chapter, a methodology is presented to identify secondary incidents. A real time incident video is used as a case study to show the impacts caused by primary incidents.

4.1 Case Study Video

Prior to developing a methodology to identify secondary incidents, a clear understanding of what secondary incidents are, which incidents are to be considered as secondary and the factors influencing the occurrence of secondary incidents are essential. On the contrary, the review on secondary incidents presented in chapter 3 clearly lacks accuracy in defining the secondary incidents. Moreover, the factors influencing the occurrence of secondary incidents are not studied properly. Therefore, a comprehensive study on the factors influencing the secondary incidents and their impact on real time traffic is presented in this chapter.

Apparently, it is known that secondary incidents are caused only due to the occurrence of primary incidents. Thus, the impacts caused by primary incidents on freeways are to be identified first. It is obvious that the traffic congestion in the incident direction increases as incident time progresses. Furthermore, there is a rubbernecking effect another side of the freeway when an incident occurs. These two impacts are generally seen or taken into consideration in many studies but, real time scenario creates more impacts than discussed. In a attempt to identify the impacts of primary incidents, a real time incident is analyzed and presented as a case study in this chapter. This video
absolutely demonstrates the enormous impacts created by primary incidents and the need of good incident management plan.

This video is provided by Washington state DOT from traffic operation center in north Seattle. It describes an incident that occurred on January 4th 2002 at 2:55 in the afternoon at the intersection of interstate 405 and interstate 5 near the Lynnwood areas demonstrated in Figure 4.1.

![Figure 4.1: The intersection of Linwood area 405 and interstate 5 in north Seattle.](image)
Green indicates normal traffic flow (at or near speed limit); black indicates stop and go’s; red indicates heavy traffic; yellow signifies traffic flow below the speed limit and blue indicates a segment that is not instrumented. Incident takes place at 2.55 p.m. on I-5 near the interchange as illustrated by the arrow in figure 4.2. Three lanes are affected on a 4-lane freeway due to this incident and queue is formed in a few minutes after the occurrence of the incident.

Figure 4.2: An accident takes occurred at 2:55 pm
This video clearly demonstrates the impact of emergency lights on the opposite side of freeway. A queue length of 2 to 3 miles is formed on the other side of the freeway just because of the emergency lights. This effect is known as “rubbernecking” and is depicted by an arrow in figure 4.3.

![Figure 4.3: Queue length formed in the opposite direction due to rubbernecking](image)

After approximately 20 minutes, the backup in the direction of the incident extended to over 12 miles as shown in Figure 4.4.
The incident scene is almost cleared 35 minutes from the time of occurrence. However, the queue expanded to about ten miles. The queue is continuously increasing as depicted in Figure 4.5. The incident scene is completely cleared at 3:40 p.m but still the traffic backup is continuously increasing. The traffic congestion is seen right around King County at 4:40 p.m. depicted in figure 4.5, which is about 12 miles away from the original incident scene. Whereas, the congestion at the incident scene is almost resolved.
Figure 4.5: Progression of the queue after the incident clearance, it extends to 12 miles even after an hour from clearance

Even though no secondary incidents have occurred in this video, it clearly shows the large dynamic impact of freeway incidents in both directions. For instance, if another incident has occurred at 3:40 p.m or outside the backup of 1 mile, it would not have been considered a secondary incident. This follows the conventionally used definition of secondary events which follow static thresholds (less than 1 mile and clearance time plus 15 minutes).
This video not only demonstrates the large dynamic impact of freeway incidents but also shows the lack of proper training to the incident management team. Review of this incident by incident management personnel reveals that this incident can be managed in a better way. For instance, an incident is occurred on the left most lane, but the fire truck is parked on the right most lane which is 3 lanes away from the incident and the emergency lights were stopped ten minutes after the clearance of incidents. The effects observed in this video are studied further using simulations and these effects are applied to real time crash data to identify secondary incidents.

4.1.1 Identified impacts of primary incidents

The video demonstrated in section 4.1 shows the large dynamic nature of queue information on both sides of the freeway. The possible effects of primary incidents observed in the video are listed below.

Three types of impacts are identified due to the occurrence of primary incident:

1. Formation of queue even after the incident is cleared
2. Congestion on the other side of the freeways due to the primary incident (rubbernecking)
3. Dynamic movement of distraction point in opposite direction with respect to the queue gets cleared in the incident direction.

As there is no real time information available on the formation of queue once an incident has occurred, the above said impacts will be studied using VISSIM software. Simulations are carried out for different sets of traffic volumes such as heavy, medium and low traffic. Historic data of traffic volumes in Las Vegas region is considered to study the impacts created by the above factors.
4.2 Data

Different sets of data are to be accumulated in order to perform simulations to study the impacts of primary incidents and to develop a methodology to identify the number of secondary incidents. The data used in this thesis is described below.

(a) Crash data: Crash data contains the accidents that occurred on Nevada freeways. This is data was provided by the Nevada highway patrol (NHP) which manages I-15, US-95 and I-215. These files contain different fields such as accident number, even after an hour from clearance date, primary street, secondary street, weather, receive time, clear time, management time etc. Sample of these data is shown in figure 4.6. The data from 2005 to 2009 are used in this study.

(b) Traffic Volume data: VISSIM uses the traffic volume as the input to calculate the queue length formed after an incident occurs. Therefore, Traffic volume data is

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![Data sample](image-url)

**Figure 4.6: Data sample**
obtained from the Annual Average traffic data report published by NDOT. This data consists of an average traffic on a freeway for a period of 24hrs. The screen shot of traffic volume data is shown in figure 4.7.

<table>
<thead>
<tr>
<th>Station</th>
<th>Route / Location</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>0030001</td>
<td>I-15, S/B off-ramp of the Primm Intch 'Exit 1'.</td>
<td>7,159</td>
<td>8,620</td>
<td>9,420</td>
<td>9,850</td>
<td>9,300</td>
<td>8,900</td>
</tr>
<tr>
<td>0030002</td>
<td>I-15, S/B on-ramp of the Primm Intch 'Exit 1'.</td>
<td>5,409</td>
<td>5,180</td>
<td>4,330</td>
<td>5,260</td>
<td>4,300</td>
<td>4,200</td>
</tr>
<tr>
<td>0030003</td>
<td>I-15, S/B off-ramp of the IR-215 Intch to Las Vegas Bl.</td>
<td>3,459</td>
<td>3,400</td>
<td>4,200</td>
<td>4,850</td>
<td>5,000</td>
<td>5,500</td>
</tr>
<tr>
<td>0030004</td>
<td>Lost City Museum Rd, 70' W of SR-199 (Moapa Vly Rd).</td>
<td>110</td>
<td>310</td>
<td>370</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>0030005</td>
<td>I-15, N/B off-ramp of the Primm Intch 'Exit 1' 150' S of the cross traffic rd.</td>
<td>5,000</td>
<td>5,050</td>
<td>4,000</td>
<td>4,850</td>
<td>4,500</td>
<td>4,400</td>
</tr>
<tr>
<td>0030006</td>
<td>I-15, N/B on-ramp of the Primm Intch 'Exit 1' 150' N of the cross traffic rd.</td>
<td>6,750</td>
<td>6,760</td>
<td>6,600</td>
<td>7,100</td>
<td>6,600</td>
<td>6,200</td>
</tr>
<tr>
<td>0030007</td>
<td>SR-162, Sunset Rd., 2 mi W of Pecos Rd.</td>
<td>23,500</td>
<td>32,000</td>
<td>34,500</td>
<td>35,000</td>
<td>35,000</td>
<td>32,000</td>
</tr>
<tr>
<td>0030008</td>
<td>I-15, N/B off-ramp of the Jean Intch 'Exit 12' 400' S of the cross traffic rd.</td>
<td>1,750</td>
<td>1,900</td>
<td>1,650</td>
<td>1,650</td>
<td>1,500</td>
<td>1,300</td>
</tr>
<tr>
<td>0030010</td>
<td>PCC87, Apex Frontage Rd., 2 mi S of US-93.</td>
<td>2,000</td>
<td>1,900</td>
<td>2,150</td>
<td>2,250</td>
<td>1,700</td>
<td>1,700</td>
</tr>
<tr>
<td>0030011</td>
<td>SR-162, Las Vegas Bl., 2 mi N of SR-161.</td>
<td>1,400</td>
<td>1,000</td>
<td>1,100</td>
<td>1,200</td>
<td>1,700</td>
<td>1,000</td>
</tr>
<tr>
<td>0030013</td>
<td>I-15, N/B on-ramp of the Jean Intch 'Exit 12' 300' N of SR-161.</td>
<td>2,450</td>
<td>2,500</td>
<td>2,550</td>
<td>2,550</td>
<td>2,200</td>
<td>1,900</td>
</tr>
<tr>
<td>0030014</td>
<td>I-15, S/B off-ramp of the Jean Intch 'Exit 12' .1 mi N of SR-161.</td>
<td>3,050</td>
<td>3,400</td>
<td>3,300</td>
<td>3,350</td>
<td>3,100</td>
<td>2,400</td>
</tr>
</tbody>
</table>

Figure 4.7: sample AADT data

(c) Queue information: Queue information is the numerical study of different types of impacts identified in the case study video. This information is used to identify the secondary incidents. Queue formed due to the 3 factors mentioned in section 4.2 are simulated using VISSIM.
4.3 Methodology

The factors influencing the occurrence of secondary incidents are described in section 4.2. Therefore, secondary incidents are defined as any incident that occurred due to the impacts provided by primary incidents. A methodology to numerically define the boundaries which takes care of all the three impacts are presented in this section.

(a) In the crash data provided by NHP, location of incident is recorded in terms of cross street names. This information is converted in a manner that the location is represented in miles. Further information is included in chapter 5

(b) Since traffic volume is not uniform all day, the given data is categorized into three files according to the time of the incident during the day. The categorization criteria is given below

- Traffic volume is considered to be peak between 7 a.m. to 11 a.m. and 4 p.m. to 7 p.m.
- Traffic volume is considered to be moderate between 12 noon to 3 p.m. and 8 p.m. to 10 p.m.
- Traffic volume is considered to be low between 10 p.m. to 7 a.m.

(c) The queue length formed in three different scenarios is estimated by using traffic volume in VISSIM. An average traffic volume is obtained from AADT data. This data is used to estimate the peak and low traffic volumes, using least mean square estimation method.

(d) Using the traffic volumes obtained in step (c), VISISM simulations are carried out to estimate the queue lengths formed for the three different traffic volumes. An average increase in queue length per minute is calculated. Let us consider $Q_{\text{inc}}$
and $Q_{deca}$, $Q_{inco}$ and $Q_{deco}$ as the average increment and decrement of queue per minute in both directions of the freeway.

(e) Files obtained in step b are filtered according to the date and freeway number.

(f) The queue length is calculated with an increment of 15 minutes until the clearance time provided for an incident in the crash data is reached i.e., $Q_{15}$, $Q_{30}$, $Q_{45}$......$Q_{\text{cleartime}}$, whereas

$$Q_{15} = 15 \times Q_{inca}$$

Similarly, in opposite direction

$$Q_{15} = 15 \times Q_{inco}$$

Likewise, $Q_{30}$, $Q_{45}$......$Q_{\text{cleartime}}$ are calculated.

The time taken to clear the incident is calculated as follows

$$t_{\text{cleara}} = \frac{Q_{\text{cleartime}}}{Q_{deca}}$$

Similarly, in opposite direction

$$t_{\text{clearo}} = \frac{Q_{\text{cleartime}}}{Q_{deco}}$$

Where $t_{\text{cleara}}$ and $t_{\text{clearo}}$ are the times taken to clear the queue after incident is removed.

The important feature observed in the video is formation of queue even after the incident is cleared. This effect is calculated as follows

$$Q_{\text{tcleara}} = t_{\text{cleara}} \times Q_{inca}$$

Similarly, in opposite direction

$$Q_{\text{tclearo}} = t_{\text{clearo}} \times Q_{inco}$$

And queue decrement after the incident is cleared is

$$Q_{d5} = 5 \times Q_{deca}$$
Here $Q_{d5}$ represents the decrement of queue for every 5 minutes.

These calculations ensure the dynamic nature of queue formation and queue clearances the time progresses. This process is repeated for all the incidents.

(g) Boundary conditions required to identify the secondary conditions are given as follows:

- Temporal boundaries: Time at beginning of the incident and clearance time along with the time calculated to clear the queue are taken as lower and upper boundaries respectively. Here the upper limit is dynamic as discussed in step(f).
  
  Lower boundary: $t_{\text{begin}}$
  
  Upper boundary: $t_{\text{begin}}+t$
  
  Where $t$ is incremented with a 15 minute interval i.e., 15, 30, 45..... $t_{\text{resolved}}$

  Here $t_{\text{begin}}$ is the time of beginning of the incident and $t_{\text{resolved}}$ is the time taken to resolve the queue completely.

- Spatial boundaries: Location of the incident and location of the incident along with the queue formed in both directions are used as lower and upper boundaries respectively. Here the upper boundary is dynamic as the queue length is calculated for every 15 minutes until the time reaches clearance time of the incident.

  Lower boundary: $L_{\text{inci}}$ (till clearance time) and $L_{\text{inci}}-Q_{d5}$ (after clearance time)
  
  Upper boundary: $L_{\text{inci}}+Q_{\text{acc}}$ (in accident direction)

  Lower boundary: $L_{\text{inci}}$ (till clearance time) and $L_{\text{inci}}+Q_{d5}$ (After clearance time)

  Upper boundary: $L_{\text{inci}}+Q_{\text{opp}}$ (in opposite direction)
Where $Q_{acc}$ and $Q_{acc}$ is incremented with a 15 minutes interval i.e., $Q_{15}$, $Q_{30}$, $Q_{45}$......$Q_{t\text{clear}}$

Here $L_{inci}$ is the location of the incident; $Q_{acc}$ and $Q_{opp}$ are the queue lengths variation in both of the freeway as time progresses
CHAPTER 5
SIMULATIONS

In this chapter, the simulations and calculations required to perform the steps discussed in section 4.3 are presented.

5.1 Representing the incident location in terms of miles

The crash data provided by NHP represents the location in-terms of cross street names. Thus, in order to filter the data based on the spatial parameter using matlab, it is necessary to convert the location information into miles. Freeways within the Clark County district are considered. The location of incident while approaching towards north (north bound) as well as south direction (South bound) are calculated and presented in the tables 5.1, 5.2 and 5.3. These tables are used to represent the accident location in terms of miles.

5.2 Peak, Moderate and Low Traffic Volume Estimation

As presented in step (c) in section 4.3, traffic volumes are necessary to estimate the queue lengths using VISISM. In order to make the simulation results more meaningful and much closer to the real time scenario, a real time traffic data with minute details such as traffic variation at different locations as well as change of traffic demand according to the time of day is taken into consideration. AADT and MADT data are used to estimate traffic volumes according to the time of the day.
<table>
<thead>
<tr>
<th>Primary Street</th>
<th>Secondary Street</th>
<th>North Bound</th>
<th>South Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-15</td>
<td>SR-161</td>
<td>0</td>
<td>41.5</td>
</tr>
<tr>
<td>I-15</td>
<td>S. Las Vegas blvd</td>
<td>13.2</td>
<td>26</td>
</tr>
<tr>
<td>I-15</td>
<td>SR-146</td>
<td>15.5</td>
<td>26</td>
</tr>
<tr>
<td>I-15</td>
<td>Blue Diamond/160</td>
<td>21.2</td>
<td>20.3</td>
</tr>
<tr>
<td>I-15</td>
<td>Warm Spring</td>
<td>22.2</td>
<td>19.3</td>
</tr>
<tr>
<td>I-15</td>
<td>I-215</td>
<td>22.6</td>
<td>18.9</td>
</tr>
<tr>
<td>I-15</td>
<td>Sunset/SR-562</td>
<td>23.1</td>
<td>18.4</td>
</tr>
<tr>
<td>I-15</td>
<td>Russel/SR-594</td>
<td>24.1</td>
<td>17.4</td>
</tr>
<tr>
<td>I-15</td>
<td>Tropicana/SR-593</td>
<td>25.6</td>
<td>15.9</td>
</tr>
<tr>
<td>I-15</td>
<td>Flamingo/SR-592</td>
<td>26.5</td>
<td>15</td>
</tr>
<tr>
<td>I-15</td>
<td>Spring Mountain Rd</td>
<td>27.2</td>
<td>14.3</td>
</tr>
<tr>
<td>I-15</td>
<td>Desert Inn</td>
<td>27.5</td>
<td>14</td>
</tr>
<tr>
<td>I-15</td>
<td>Sahara/SR-589</td>
<td>28.6</td>
<td>12.9</td>
</tr>
<tr>
<td>I-15</td>
<td>Charleston/SR-159</td>
<td>29.8</td>
<td>11.7</td>
</tr>
<tr>
<td>I-15</td>
<td>Speed Way</td>
<td>41.5</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5.1: I-15 cross street locations in terms of miles
<table>
<thead>
<tr>
<th>Primary Street</th>
<th>Secondary Street</th>
<th>North Bound</th>
<th>South Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>US-95</td>
<td>Foothills Drove</td>
<td>0</td>
<td>37.4</td>
</tr>
<tr>
<td>US-95</td>
<td>College Drive</td>
<td>2.4</td>
<td>35</td>
</tr>
<tr>
<td>US-95</td>
<td>I-215/Leak Mead</td>
<td>6.2</td>
<td>31.2</td>
</tr>
<tr>
<td>US-95</td>
<td>Sunset Rd/SR-562</td>
<td>8.6</td>
<td>28.8</td>
</tr>
<tr>
<td>US-95</td>
<td>Russel/SR-594</td>
<td>10.3</td>
<td>27.1</td>
</tr>
<tr>
<td>US-95</td>
<td>Tropicana/SR-593</td>
<td>12.6</td>
<td>24.8</td>
</tr>
<tr>
<td>US-95</td>
<td>Flamingo/SR-592</td>
<td>13.6</td>
<td>23.8</td>
</tr>
<tr>
<td>US-95</td>
<td>Charleston/SR-159</td>
<td>16.8</td>
<td>20.6</td>
</tr>
<tr>
<td>US-95</td>
<td>MLK</td>
<td>21.2</td>
<td>16.2</td>
</tr>
<tr>
<td>US-95</td>
<td>Summerlin/SR-595</td>
<td>25.9</td>
<td>11.5</td>
</tr>
<tr>
<td>US-95</td>
<td>Lake Mead blvd/147</td>
<td>27.3</td>
<td>10.1</td>
</tr>
<tr>
<td>US-95</td>
<td>Cheyenne/SR-574</td>
<td>28.8</td>
<td>8.6</td>
</tr>
<tr>
<td>US-95</td>
<td>I-215</td>
<td>33.2</td>
<td>4.2</td>
</tr>
<tr>
<td>US-95</td>
<td>Durango</td>
<td>34.9</td>
<td>2.5</td>
</tr>
<tr>
<td>US-95</td>
<td>Kyle Canyon Rd.</td>
<td>37.4</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5.2: US-95 cross street locations in terms of miles
AADT is the annual average daily traffic volume on a particular highway or road. It gives the average traffic volume per day. The peak, moderate and low traffic volumes are estimated from an average traffic volume because the traffic volume varies greatly during mornings and evenings when compared to night time. MADT is the monthly average daily traffic of a particular highway or road. This data consists of traffic volumes for every hour at a particular location. From this peak, moderate and low traffic volumes are obtained. There is a lack of data for every location and even at that location data is collected only for a week in the whole year. So, a least mean square method is used to obtain a generalized relation peak, moderate and low traffic volumes.

5.2.1 Least Mean Square Estimation Method

Least mean square method estimates the values of the dependent variable from the values of independent variables. This principle states that if \( y \) is a linear function of an independent variable \( x \), the most probable position of a line \( y' = a' + b'x \) is such that the sum of squares of deviations of all points \( (x_i, y_i) \) from the line is a minimum; the deviations are measured in the direction of \( y \) axis [11] [27] [8].

Let us consider that we have \( n \) pairs of values

\[
\begin{cases}
  x_1, x_2, x_3, \ldots, x_n \\
y_1, y_2, y_3, \ldots, y_n
\end{cases}
\]
<table>
<thead>
<tr>
<th>Primary Street</th>
<th>Secondary Street</th>
<th>North Bound</th>
<th>South Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-15</td>
<td>SR-161</td>
<td>0</td>
<td>41.5</td>
</tr>
<tr>
<td>I-15</td>
<td>S. Las Vegas blvd</td>
<td>13.2</td>
<td>26</td>
</tr>
<tr>
<td>I-15</td>
<td>SR-146</td>
<td>15.5</td>
<td>26</td>
</tr>
<tr>
<td>I-15</td>
<td>Blue Diamond/160</td>
<td>21.2</td>
<td>20.3</td>
</tr>
<tr>
<td>I-15</td>
<td>Warm Spring</td>
<td>22.2</td>
<td>19.3</td>
</tr>
<tr>
<td>I-15</td>
<td>I-215</td>
<td>22.6</td>
<td>18.9</td>
</tr>
<tr>
<td>I-15</td>
<td>Sunset/SR-562</td>
<td>23.1</td>
<td>18.4</td>
</tr>
<tr>
<td>I-15</td>
<td>Russel/SR-594</td>
<td>24.1</td>
<td>17.4</td>
</tr>
<tr>
<td>I-15</td>
<td>Tropicana/SR-593</td>
<td>25.6</td>
<td>15.9</td>
</tr>
<tr>
<td>I-15</td>
<td>Flamingo/SR-594</td>
<td>26.5</td>
<td>15</td>
</tr>
<tr>
<td>I-15</td>
<td>Spring Mountain Rd</td>
<td>27.2</td>
<td>14.3</td>
</tr>
<tr>
<td>I-15</td>
<td>Desert Inn</td>
<td>27.5</td>
<td>14</td>
</tr>
<tr>
<td>I-15</td>
<td>Sahara/SR-589</td>
<td>28.6</td>
<td>12.9</td>
</tr>
<tr>
<td>I-15</td>
<td>Charleston/SR-159</td>
<td>29.8</td>
<td>11.7</td>
</tr>
<tr>
<td>I-15</td>
<td>Speed Way</td>
<td>41.5</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5.2: US-95 cross street locations in terms of miles
<table>
<thead>
<tr>
<th>Primary Street</th>
<th>Secondary Street</th>
<th>North Bound</th>
<th>South Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-215</td>
<td>US-95</td>
<td>0</td>
<td>29.6</td>
</tr>
<tr>
<td>I-215</td>
<td>Valle Verde</td>
<td>3.3</td>
<td>26.3</td>
</tr>
<tr>
<td>I-215</td>
<td>Eastern</td>
<td>6.4</td>
<td>23.2</td>
</tr>
<tr>
<td>I-215</td>
<td>Windmill</td>
<td>8.2</td>
<td>21.4</td>
</tr>
<tr>
<td>I-215</td>
<td>Warm Spring</td>
<td>9.3</td>
<td>20.3</td>
</tr>
<tr>
<td>I-215</td>
<td>Las Vegas Blvd</td>
<td>11.2</td>
<td>18.4</td>
</tr>
<tr>
<td>I-215</td>
<td>I-15</td>
<td>11.6</td>
<td>18</td>
</tr>
<tr>
<td>I-215</td>
<td>Rainbow</td>
<td>15</td>
<td>15.6</td>
</tr>
<tr>
<td>I-215</td>
<td>Durango</td>
<td>17</td>
<td>12.6</td>
</tr>
<tr>
<td>I-215</td>
<td>Russell</td>
<td>18.7</td>
<td>10.9</td>
</tr>
<tr>
<td>I-215</td>
<td>Tropicana</td>
<td>19.8</td>
<td>9.8</td>
</tr>
<tr>
<td>I-215</td>
<td>Flamingo</td>
<td>21</td>
<td>8.6</td>
</tr>
<tr>
<td>I-215</td>
<td>Desert Inn</td>
<td>23.1</td>
<td>6.5</td>
</tr>
<tr>
<td>I-215</td>
<td>Charleston/SR-159</td>
<td>25.1</td>
<td>4.5</td>
</tr>
<tr>
<td>I-215</td>
<td>Cheyenne Ave</td>
<td>29.6</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5.3: I-215 cross street locations in terms of miles
A best regression line is to be estimated such that the sum of squares of deviation from should be minimum. This can be achieved by using a simple regression equation

\[ y' = a' + b'x \]

The error term, between the original values and the estimated values is given by

\[ e_i = y_i - (a' + b'x_i) \]

Sum of squares of error term is given as

\[ P = \sum_{i=1}^{n} e_i^2 \]

To satisfy the sum of squares of deviation to be minimum i.e., \( R \) is minimum, we have to perform

\[
\begin{aligned}
\frac{\partial P}{\partial a'} &= 0 \\
\frac{\partial P}{\partial b'} &= 0 
\end{aligned}
\]

Solving the above two equations gives

\[ b' = \frac{\sum(x_i - X)(y_i - Y)}{\sum(x_i - X)^2} \]

\[ a' = Y - b'X \]

Where \( X \) and \( Y \) are the means of \( x_i \) and \( y_i \) respectively.

The coefficient of determination measures the quality of a fitted equation and is given by

\[ R^2 = \frac{\sum(y_i - Y)^2 - \sum(y_i - y_i')^2}{\sum(y_i - Y)^2} \]
Calculations made to estimate the peak traffic volume is given in table 5.4

<table>
<thead>
<tr>
<th>Max. Vol. ($y_i$)</th>
<th>Ave Vol. ($x_i$)</th>
<th>($x_i-X$)</th>
<th>($y_i-Y$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14149</td>
<td>8370</td>
<td>1394.5</td>
<td>1772.74</td>
</tr>
<tr>
<td>16305</td>
<td>9588</td>
<td>2612.5</td>
<td>3928.74</td>
</tr>
<tr>
<td>17317</td>
<td>10272.5</td>
<td>3297</td>
<td>4940.74</td>
</tr>
<tr>
<td>15630</td>
<td>9793</td>
<td>2817.5</td>
<td>3253.74</td>
</tr>
<tr>
<td>14070</td>
<td>8230</td>
<td>1254.5</td>
<td>1693.74</td>
</tr>
<tr>
<td>14352</td>
<td>8010</td>
<td>1034.5</td>
<td>1975.74</td>
</tr>
<tr>
<td>13481</td>
<td>7560</td>
<td>584.5</td>
<td>1104.74</td>
</tr>
<tr>
<td>14053</td>
<td>7729</td>
<td>753.5</td>
<td>1676.74</td>
</tr>
<tr>
<td>11047</td>
<td>6095.5</td>
<td>-880</td>
<td>-1329.26</td>
</tr>
<tr>
<td>9836</td>
<td>5443.5</td>
<td>-6975.5</td>
<td>-2540.26</td>
</tr>
<tr>
<td>10369</td>
<td>5669</td>
<td>-1306.5</td>
<td>-2007.26</td>
</tr>
<tr>
<td>10776</td>
<td>5819.5</td>
<td>-1156</td>
<td>-1600.26</td>
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<tr>
<td>11138</td>
<td>5953.5</td>
<td>-1022</td>
<td>-1238.26</td>
</tr>
<tr>
<td>9480</td>
<td>5185</td>
<td>-1790.5</td>
<td>-2896.26</td>
</tr>
<tr>
<td>9191</td>
<td>5141.5</td>
<td>-1834</td>
<td>-3185.26</td>
</tr>
</tbody>
</table>

Table 5.4: Estimation of peak traffic volume
Variables a and b are calculated as

\[ b = 1.02 \]
\[ a = 5221.6119 \]

Linear equation to estimate the peak traffic volume is

\[ y = 5221.6119 + 1.02(x_i) \]

Coefficient of determination \( R^2 = 84.6 \%

Calculations made to estimate the moderate traffic volume is given in table 5.5

Variables ‘a’ and ‘b’ are given calculates as

\[ b = 1.04 \]
\[ a = 631.53 \]

Linear equation to estimate the moderate traffic volume is

\[ y = 631.53 + 1.04(x_i) \]

Coefficient of determination \( R^2 = 70.6 \%

Calculations made to estimate the low traffic volume is given in table 5.6

Variables ‘a’ and ‘b’ are given calculates as

\[ b = 0.346 \]
\[ a = -839.375 \]

Linear equation to estimate the low traffic volume is

\[ y = -839.375 + 0.346(x_i) \]

Coefficient of determination \( R^2 = 78.9 \%\)
<table>
<thead>
<tr>
<th>Mod. Vol. (y_i)</th>
<th>Ave Vol. (x_i)</th>
<th>(x_i-X)</th>
<th>(y_i-Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9952</td>
<td>8370</td>
<td>1394.5</td>
<td>1366</td>
</tr>
<tr>
<td>12050</td>
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<td>3498</td>
</tr>
<tr>
<td>11726</td>
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<td>2817.5</td>
<td>3140</td>
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<td>-269</td>
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<td>7582</td>
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<td>-2351</td>
</tr>
<tr>
<td>6552</td>
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</tr>
<tr>
<td>7360</td>
<td>5141.5</td>
<td>-1834</td>
<td>-1226</td>
</tr>
</tbody>
</table>

Table 5.5: Estimation of moderate traffic volume
<table>
<thead>
<tr>
<th>Min. Vol. ( (y_i) )</th>
<th>Ave Vol. ( (x_i) )</th>
<th>( (x_i-X) )</th>
<th>( (y_i-Y) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>14149</td>
<td>8370</td>
<td>1394.5</td>
<td>1016.78</td>
</tr>
<tr>
<td>16305</td>
<td>9588</td>
<td>2612.5</td>
<td>1296.78</td>
</tr>
<tr>
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<td>10272.5</td>
<td>3297</td>
<td>1653.78</td>
</tr>
<tr>
<td>15630</td>
<td>9793</td>
<td>2817.5</td>
<td>2381.78</td>
</tr>
<tr>
<td>14070</td>
<td>8230</td>
<td>1254.5</td>
<td>815.78</td>
</tr>
<tr>
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<td>8010</td>
<td>1034.5</td>
<td>93.78</td>
</tr>
<tr>
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<td>7560</td>
<td>584.5</td>
<td>64.78</td>
</tr>
<tr>
<td>14053</td>
<td>7729</td>
<td>753.5</td>
<td>-169.22</td>
</tr>
<tr>
<td>11047</td>
<td>6095.5</td>
<td>-880</td>
<td>-430.22</td>
</tr>
<tr>
<td>9836</td>
<td>5443.5</td>
<td>-6975.5</td>
<td>-523.22</td>
</tr>
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<td>5669</td>
<td>-1306.5</td>
<td>-605.22</td>
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<td>-1156</td>
<td>-711.22</td>
</tr>
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<td>5953.5</td>
<td>-1022</td>
<td>-805.22</td>
</tr>
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<tr>
<td>9191</td>
<td>5141.5</td>
<td>-1834</td>
<td>-482.22</td>
</tr>
</tbody>
</table>

Table 5.6: Estimation of low traffic volume
The average traffic volume on a freeway using AADT data at any location is observed to be 8000 vph. Therefore using the least mean square estimation the peak, low and moderate traffic volumes are estimated at 12000, 2000 and 9000 respectively.

5.3 VISSIM

VISSIM is used to simulate three types of impacts caused by primary incidents in terms of time, queue formed and queue cleared as discussed in section 4.1.1

VISSIM is a microscopic, behavior-based multi-purpose traffic simulation program. VISSIM is a microscopic multi-modal traffic flow simulation software. It is developed by PTV Planung Transport Verkehr AG in Karlsruhe, Germany. It offers a wide variety of urban and highway applications, integrating public and private transportation. In addition to an accurate representation of the roadway network, it is also important for the simulation model to replicate actual traffic characteristics in the area being modeled, especially the stochastic nature of traffic flow. To enable traffic representation in a detailed level, VISSIM allows modeling various vehicle types and vehicle classes rather than simply cars and trucks. Each vehicle type has a vehicle model distribution associated with it, such that different vehicles of same type will share the same acceleration/deceleration profile and average occupancy but they can have different lengths and appearances. One or more vehicle types can be combined in one vehicle class, with a similar driving behavior such as desired speed or in response to traffic controls. At the end, vehicle inputs (traffic volume) to VISSIM can consist of an array of vehicle types with relative flow making up the percentages of total traffic composition. To reflect the stochastic nature of traffic, a range of parameters associated with vehicle types and classes in VISSIM are defined as a distribution rather than a single value. The
main distribution types are desired speed, dwell time, vehicle model, color, and weight
and power (relevant for trucks only). In addition the acceleration and deceleration values
of vehicles are defined as functions of the speed. Among them, desired speed and vehicle
model distributions are the basic needs for a working VISSIM model. Figure 5.1 shows
the model of the freeway used for simulations which consists of a two way segment and
four lanes each.

Figure 5.1: Section of freeway showing the location of incident

Screen shot of simulating the incident on a freeway in VISSIM is shown in figure 5.2.
A 6 mile freeway of four lanes each in both the directions is designed in VISSIM. Traffic volumes obtained by using least mean square estimation are used as an input to the VISSIM. A red bar across the freeway shown in figure 5.2 represents the location of occurrence of an incident. The queue formation in the incident direction and congestion in the opposite direction is clearly shown in the figure.

Figure 5.2: Section of freeway used in VISSIM

5.3.1 Simulation of the Secondary Congestion in the Same Direction as the Primary Incident

An essential effect observed from the Seattle incident is the increase of queue length long after the incident is removed. The queue length increased as much as twelve miles
even an hour after the incident scene is being cleared. The cause of such congestion may not be recognized as the primary incident; yet, it is. Therefore any incidents that fall within this secondary congestion shall be considered a secondary event. Through simulations, the effect of incident is carried out. To better study the dynamic nature of progression curves for queues, apart from the queue length, the locations of the front and back of the queue are also tracked until traffic is back to normal conditions. A four lane segment of the I-15 in the Las Vegas region is simulated using the average traffic volume of 12000 vehicles/hour and an incident clearance time of 30 minutes. The bold values in the tables represent the clearance time with associated location of the queue.

Figure 5.3: Queue formed in the direction of primary incident
<table>
<thead>
<tr>
<th>Time</th>
<th>12000 VPH</th>
<th>9000 VPH</th>
<th>2000 VPh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Qfront</td>
<td>Qback</td>
<td>Qfront</td>
</tr>
<tr>
<td>6</td>
<td>6.27</td>
<td>6.27</td>
<td>6.27</td>
</tr>
<tr>
<td>10</td>
<td>6.27</td>
<td>5.76</td>
<td>6.27</td>
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<td>14</td>
<td>6.27</td>
<td>5.19</td>
<td>6.27</td>
</tr>
<tr>
<td>18</td>
<td>6.27</td>
<td>4.6</td>
<td>6.27</td>
</tr>
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<td>22</td>
<td>6.27</td>
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<td>3.43</td>
<td>6.27</td>
</tr>
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<td>6.27</td>
<td>2.9</td>
<td>6.27</td>
</tr>
<tr>
<td>34</td>
<td>5.87</td>
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</tr>
<tr>
<td>38</td>
<td>4.72</td>
<td>1.89</td>
<td>4.83</td>
</tr>
<tr>
<td>42</td>
<td>3.63</td>
<td>1.41</td>
<td>3.75</td>
</tr>
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<td>46</td>
<td>2.56</td>
<td>0.91</td>
<td>2.95</td>
</tr>
<tr>
<td>50</td>
<td>1.47</td>
<td>0.53</td>
<td>2.95</td>
</tr>
<tr>
<td>54</td>
<td>0.40</td>
<td>0.18</td>
<td>2.95</td>
</tr>
<tr>
<td>55</td>
<td>0.18</td>
<td>0.6</td>
<td>2.95</td>
</tr>
</tbody>
</table>

Table 5.7: Tracking the locations of front and back of the queue in incident direction
The graph in Figure 5.3 shows the movement of the front and back of the queue as the time progresses when 2 lanes are blocked for different traffic volumes. Graph shows that the front of the queue is constant and back of the queue is gradually increasing until the accident is cleared. Once the accident is removed the front of the queue gradually clears but at the same time the back of the queue is increasing at the same rate. It is observed that after the incident was removed, the queue kept increasing for 22 minutes with the back of the queue reaching 1.79 miles. Note that such congestion would not have been considered secondary according to previous definitions (less than one mile). However, it is found to be occurring purely due to the primary incident.

5.3.2 Simulation of the Effect of the Primary Incident on the Opposing Traffic

As discussed in previous sections, the impact of primary incidents on the other side of the freeway must also be studied. It is a common phenomenon for the opposing traffic to slowdown upon arriving on an incident scene out of curiosity or even cautiousness. The traffic in the opposite direction is affected by a certain factor which depends on various parameters such as incident visibility, type of incident, and driver curiosity. The “rubbernecking” effect is simulated by reducing the speed limit of the opposite freeway to 30mph. Furthermore, different traffic volumes are also taken into account to study the effect and congestion behavior for low (2000vph), medium (9000vph) and heavy traffic (12000vph).

Simulation results shown in Table 5.8 indicate that the congestion can increase up to one mile based on the traffic. This effect continues even after the incident is removed. The graph 5.4 shows the front and back of the queue on the other side of the freeway. The front location of the congestion point is static; however, based on the traffic conditions,
the back of the queue is fluctuating. The maximum queue formed in this simulation is approximately 0.25 miles.

![Figure 5.4: congestion on the other side of the freeway for less traffic](image)

The table in 5.9 gives the simulation results whereas the graph in Figure 5.5 demonstrates the effect of congestion when the traffic is moderate. The front location is where the drivers get distracted and slow down the vehicle. Is depicted in the graph, the location of the back of the queue is fluctuating with respect to the traffic volume. The maximum queue reached 0.7 miles in length for a moderate traffic.
<table>
<thead>
<tr>
<th>Time</th>
<th>Qfront</th>
<th>Qback</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>3.15</td>
<td>3.15</td>
</tr>
<tr>
<td>3.5</td>
<td>3.15</td>
<td>3.24</td>
</tr>
<tr>
<td>5</td>
<td>3.15</td>
<td>3.27</td>
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<td>11.67</td>
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<td>3.15</td>
<td>3.28</td>
</tr>
<tr>
<td>16.67</td>
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<td>3.15</td>
</tr>
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<td>3.15</td>
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</tr>
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</tr>
<tr>
<td>30</td>
<td>3.15</td>
<td>3.35</td>
</tr>
<tr>
<td>32.5</td>
<td>3.15</td>
<td>No congestion</td>
</tr>
</tbody>
</table>

Table 5.8: Congestion on the other side of the freeway for less traffic
<table>
<thead>
<tr>
<th>Time</th>
<th>Qfront</th>
<th>Qback</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>3.15</td>
<td>3.23</td>
</tr>
<tr>
<td>3.5</td>
<td>3.15</td>
<td>3.24</td>
</tr>
<tr>
<td>5</td>
<td>3.15</td>
<td>3.3</td>
</tr>
<tr>
<td>6.67</td>
<td>3.15</td>
<td>3.38</td>
</tr>
<tr>
<td>10</td>
<td>3.15</td>
<td>3.52</td>
</tr>
<tr>
<td>11.67</td>
<td>3.15</td>
<td>3.27</td>
</tr>
<tr>
<td>15</td>
<td>3.15</td>
<td>3.38</td>
</tr>
<tr>
<td>16.67</td>
<td>3.15</td>
<td>3.34</td>
</tr>
<tr>
<td>18.33</td>
<td>3.15</td>
<td>3.26</td>
</tr>
<tr>
<td>20</td>
<td>3.15</td>
<td>3.39</td>
</tr>
<tr>
<td>23.33</td>
<td>3.15</td>
<td>3.25</td>
</tr>
<tr>
<td>25</td>
<td>3.15</td>
<td>3.32</td>
</tr>
<tr>
<td>28.33</td>
<td>3.15</td>
<td>3.28</td>
</tr>
<tr>
<td>30</td>
<td>3.15</td>
<td>3.32</td>
</tr>
<tr>
<td>32.5</td>
<td>3.15</td>
<td>3.22</td>
</tr>
</tbody>
</table>

Table 5.9: Congestion on the other side of the freeway for moderate traffic
Figure 5.5: Congestion on the other side of the freeway for moderate traffic

The effect of congestion at high traffic volumes is depicted in the graph in Figure 5.6. The simulation results are presented in table 5.10. In this case, the maximum queue reached is 1.5 miles.

Figure 5.6: Congestion on the other side of the freeway for heavy traffic
<table>
<thead>
<tr>
<th>Time</th>
<th>Qfront</th>
<th>Qback</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>3.15</td>
<td>3.24</td>
</tr>
<tr>
<td>3.5</td>
<td>3.15</td>
<td>3.25</td>
</tr>
<tr>
<td>5</td>
<td>3.15</td>
<td>3.36</td>
</tr>
<tr>
<td>8.33</td>
<td>3.15</td>
<td>3.39</td>
</tr>
<tr>
<td>10</td>
<td>3.15</td>
<td>3.43</td>
</tr>
<tr>
<td>11.67</td>
<td>3.15</td>
<td>3.51</td>
</tr>
<tr>
<td>15</td>
<td>3.15</td>
<td>3.5</td>
</tr>
<tr>
<td>18.33</td>
<td>3.15</td>
<td>3.64</td>
</tr>
<tr>
<td>20</td>
<td>3.15</td>
<td>3.58</td>
</tr>
<tr>
<td>23.33</td>
<td>3.15</td>
<td>3.64</td>
</tr>
<tr>
<td>25</td>
<td>3.15</td>
<td>3.55</td>
</tr>
<tr>
<td>28.33</td>
<td>3.15</td>
<td>3.57</td>
</tr>
<tr>
<td>30</td>
<td>3.15</td>
<td>3.83</td>
</tr>
<tr>
<td>32.5</td>
<td>3.15</td>
<td>3.44</td>
</tr>
<tr>
<td>33.33</td>
<td>3.15</td>
<td>3.39</td>
</tr>
</tbody>
</table>

Table 5.10: Congestion on the other side of the freeway for heavy traffic
5.3.3 Simulation of the Dynamic Nature of Congestion in the Opposite Direction of the Freeway

Once an incident is cleared, the starting point of the queue moves backwards which represents resolving of the queue. As the congestion is clearing up, the distraction point for the traffic on the other side of the freeway also changes. This simulation is carried out to study the dynamic nature of the congestion point as the queue gets cleared. Table 5.11 tracks the location of front and back of the queue in both directions considering heavy traffic (12000vph) in the opposite direction. Depicted in Figure 5.7, the movement of congestion point or distraction point with respect to the dynamics of the queue in the direction of the accident. Thus from the above tables the rate at which queue length is increasing or decreasing for every minute is calculated and tabulated for different scenarios are shown in table 5.13.

Table 5.7: Dynamic movement of Congestion point on the other side of the freeway
<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
<th>Accident Direction</th>
<th>Opposite Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Qfront</td>
<td>Qback</td>
<td>Qfront</td>
</tr>
<tr>
<td>5.67</td>
<td>3.15</td>
<td>3.14</td>
<td>3.15</td>
</tr>
<tr>
<td>7.33</td>
<td>3.15</td>
<td>3.09</td>
<td>3.15</td>
</tr>
<tr>
<td>12.33</td>
<td>3.15</td>
<td>2.85</td>
<td>3.15</td>
</tr>
<tr>
<td>14</td>
<td>3.15</td>
<td>2.77</td>
<td>3.15</td>
</tr>
<tr>
<td>15.67</td>
<td>3.15</td>
<td>2.7</td>
<td>3.15</td>
</tr>
<tr>
<td>19</td>
<td>3.15</td>
<td>2.52</td>
<td>3.15</td>
</tr>
<tr>
<td>20.67</td>
<td>3.15</td>
<td>2.46</td>
<td>3.15</td>
</tr>
<tr>
<td>24</td>
<td>3.15</td>
<td>2.3</td>
<td>3.15</td>
</tr>
<tr>
<td>25.67</td>
<td>3.15</td>
<td>2.21</td>
<td>3.15</td>
</tr>
<tr>
<td>29</td>
<td>3.15</td>
<td>2.05</td>
<td>3.15</td>
</tr>
<tr>
<td>32.33</td>
<td>3.15</td>
<td>1.91</td>
<td>3.15</td>
</tr>
<tr>
<td>34</td>
<td>3.15</td>
<td>1.82</td>
<td>3.15</td>
</tr>
<tr>
<td>35.67</td>
<td>3.15</td>
<td></td>
<td>2.93</td>
</tr>
<tr>
<td>39</td>
<td>2.49</td>
<td>1.57</td>
<td>2.47</td>
</tr>
<tr>
<td>42.33</td>
<td>1.82</td>
<td>1.39</td>
<td>1.76</td>
</tr>
<tr>
<td>44</td>
<td>1.46</td>
<td>1.31</td>
<td>1.83</td>
</tr>
<tr>
<td>45.33</td>
<td>1.24</td>
<td>1.24</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Table 5.11: Dynamic movement of Congestion point on the other side of the freeway
5.4 Matlab Code

The matlab code for filtering the data is written into 4 files. File 1 is used to filter the data according to date and time of the occurrence of the incident during the day. This code returns 3 excel sheets with the data categorized according to the time of the day i.e. peak, moderate and low traffic hours. File 2, File 3, File 4 are used to calculate the queue length formed and the time taken to clear the queue. The boundary conditions stated in section 4.3 are implemented in this code. Code is included in Appendix.

5.5 Results

Obtained the generalized relations to estimate traffic related parameters using least mean square estimation method. These relations give the estimate of peak, moderate and low traffic volumes from an average traffic volume.

From the VISSIM simulation, rate at which the queue length formed for the peak traffic volume in both directions is 220 and 100 m/minute. The queue length decreased in both the directions is given by 410 and 350 m/minute. The rate of movement of distraction point as the queue gets cleared is given as 410 m/minute.

Similarly, the rate at which the queue length formed for the moderate traffic volume in both directions is 163 and 77 m/minute. The queue length decreased in both the directions is given by 450 and 325 m/minute. The rate of movement of distraction point as the queue gets cleared is given as 450 m/minute.
Table 5.12: Rate of queue increased and queue decreased for different scenarios

The rate at which the queue length formed for the low traffic volume in both directions is 65 and 30 m/minute. The queue length decreased in both the directions are given by 50 and 220 m/minute. The rate of movement of distraction point as the queue gets cleared is given as 450 m/minute. Applying the above conditions to the matlab code, the secondary incidents are identified to be 23% of the total incidents and the maximum number of secondary accidents is occurred during mid-day.
CHAPTER 6
CONCLUSIONS

This thesis presented the complete study of impacts caused by freeway incidents. A real time incident occurred on interstate 5 near Seattle area is presented as a case study to examine the impacts caused by an incident on freeways. The dynamic nature of movement of front and back of the queue after the incident clearance is identified. Significant amount of “Rubbernecking” effect is observed in the opposite direction of the freeway. The congestion on the opposite side of the freeway due to rubbernecking effect is presented in this study. Another impact observed form the video is the effect on opposing traffic as the queue gets cleared in the incident direction. The distraction point for the opposing traffic is no longer remains same as the queue gets cleared. Therefore a dynamic movement of distraction point for the oncoming traffic is identified.

It is observed that the impact presented in this study has a very high potential in causing the secondary incidents. Thus, a more detailed analysis is carried out using simulation software. Review on defining and identifying the secondary incidents are presented. Review on accident statistics throughout the U.S and specifically in Nevada State is presented. Nevada State is also presented in this thesis.

Least mean square method is presented in this thesis to estimate the peak, moderate and low traffic volumes from average traffic volumes. Using these volumes, simulations are carried out to calculate the queue lengths formed by an incident in both the directions.

Finally, temporal and spatial parameters are defined, coded and implemented to identify secondary incidents. The parameters defined in this study extend well beyond the static and dynamic thresholds used in the past to identify secondary incidents. 23% of the total
incidents are identified as secondary in nature and most number of accidents are occurred during mid-day peak. Reducing the number of secondary incidents can have significant benefits to passengers, incident management programs and different agencies involved in incident management operations.
APPENDIX I

DESIGNER GUIDE

This section describes the application developed to identify secondary incidents from a crash data using matlab. The input file required for the matlab and the steps involved in using the program are discussed.

(a) This program utilizes crash data provided by the NHP. The NHP data contains the parameters such as date, accident location; receive time, clear time and clearance time as shown in figure 4.6. This data is modified such that it is compatible with matlab software. The modified data is shown in figure A.1. The first and second columns in the data represent the day and Primary Street of the incidents. The third and fourth columns represent the location of the incident while traveling northbound and southbound respectively. The remaining six columns contain the hours and minutes of incident time, clear time and clearance time. However, irrespective of the fields of collected crash data, the input file should be modified as shown in fig A.1.

<p>| | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>15</td>
<td>32.7</td>
<td>8.8</td>
<td>7</td>
<td>43</td>
<td>8</td>
<td>53</td>
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<tr>
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<td>15</td>
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<td>12.9</td>
<td>12</td>
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<td>15.9</td>
<td>13</td>
<td>36</td>
<td>15</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
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<td>15</td>
<td>26.8</td>
<td>14.7</td>
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<td>15</td>
<td>44</td>
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</tr>
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<td>16</td>
<td>34.4</td>
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<td>17</td>
<td>33</td>
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<tr>
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<td>15</td>
<td>34.4</td>
<td>7.1</td>
<td>19</td>
<td>4</td>
<td>21</td>
<td>20</td>
<td>2</td>
</tr>
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<td>15</td>
<td>25.6</td>
<td>15.9</td>
<td>22</td>
<td>26</td>
<td>23</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>15</td>
<td>28.6</td>
<td>12.9</td>
<td>6</td>
<td>52</td>
<td>8</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>25.6</td>
<td>15.9</td>
<td>14</td>
<td>9</td>
<td>15</td>
<td>42</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>28.6</td>
<td>12.9</td>
<td>14</td>
<td>30</td>
<td>15</td>
<td>35</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>25.6</td>
<td>15.9</td>
<td>14</td>
<td>46</td>
<td>16</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>22.6</td>
<td>18.9</td>
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<td>15</td>
<td>60</td>
<td>0</td>
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<td>2</td>
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<td>32.7</td>
<td>6.8</td>
<td>15</td>
<td>26</td>
<td>16</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>34.4</td>
<td>7.1</td>
<td>16</td>
<td>13</td>
<td>17</td>
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<tr>
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<td>15</td>
<td>25.6</td>
<td>12.9</td>
<td>16</td>
<td>26</td>
<td>17</td>
<td>23</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure A.1: Modified data
(b) The rate of increment and decrement of queue length per every minute for different traffic volumes are calculated. This data is utilized in the matlab program.

(c) According to the geographical area being studied, change the timings in the field ‘/* Assigning the time to separate the data*/’ provided in the program. After assigning the appropriate timings, run the ‘rohitpart1 program’. This program generates 3 files with data separated according to the time of the day.

(d) Change the values of field ‘/*Giving the miles information obtained from vissim*/’ in ‘rohitpart2’, ‘rohitpart3’ and ‘rohitpart4’ with the values obtained in step (b). Run the files ‘rohitpart2’, ‘rohitpart3’ and ‘rohitpart4’. These files generate ‘peakresults’, ‘moderateresults’ and ‘lowresults’. Each file contains the secondary incidents occurred in their respective time and traffic volumes.
The input to this program is shown in fig A.1. This program generates 3 excel files termed as peak, moderate and low. These output files contain the filtered data according to the time of the day.

clc;
clear all;
close all;

\* Input File*/
data=xlsread(‘rohitnew.xls’);

[R C]=size(data)

\* Reading the columns from the file*/
hr=data(:,5);

mr=data(:,6);

hc=data(:,7);

mc=data(:,8);

hm=data(:,9);

mm=data(:,10);

\* Assigning the time to separate the data*/
time1=(7:1:11)’;
time2=(12:1:16)’;
time3=(17:1:19)’;
time4=(20:1:24)';
time5=(0:1:6)';
ind11=1;
ind12=1;
ind13=1;

/* Filtering the data according to the time of the day*/
for q=1:R
    w1=find(hr(q,:)==time1);
    w2=find(hr(q,:)==time3);
    w3=find(hr(q,:)==time2);
    w4=find(hr(q,:)==time4);
    w5=find(hr(q,:)==time5);
    if isempty(w3)&& isempty(w4)&& isempty(w5)
        data22(ind11,:)=data(q,:);
        ind11=ind11+1;
    elseif isempty(w1) && isempty(w2)&& isempty(w4)&& isempty(w5)
        data23(ind12,:)=data(q,:);
        ind12=ind12+1;
    else
        data24(ind13,:)=data(q,:);
        ind13=ind13+1;
    end
end
\* Writing the filtered data into their respective files*/

xlswrite('peak.xls',data22);

xlswrite('moderate.xls',data23);

xlswrite('low.xls',data24);

rohitpart2

This program is utilizes the peak file obtained in `rohitpart1` as input. In this the rate of increment and decrement of queue obtained from vissim simulations are used. Boundary conditions are calculated and applied to the data in this program. The output file obtained in this part contains the secondary incidents occurred during peak period.

cle;

clear all;

close all;

\* Reading a file from the filtered data*/

data=xlsread('peak.xls');

hr22=data(:,5);

66

mr22=data(:,6);

hc22=data(:,7);

mc22=data(:,8);

hm22=data(:,9);

mm22=data(:,10);

ind21=1;

\* Converting hours to minutes*/
for i=1:length(hm22)
    tr(i,:)=((hr22(i,:))*60)+mr22(i,:);
    tc(i,:)=((hc22(i,:))*60)+mc22(i,:);
    tm(i,:)=((hm22(i,:))*60)+mm22(i,:);
end

%fw=[15;95;215];
date=data(:,1);
loc=data(:,2);
N=data(:,3);
S=data(:,4);
main=[date loc N S tr tc tm];
ind1=1;

% Filtering the data according to the location
for l1=1:length(loc)
    if loc(l1,:)==15
        data1(ind1,:)=main(l1,:);
        ind1=ind1+1;
    end
end
date3=data1(:,1);

% Separating the data according to the date
k=1;
for j=1:31
    ind=1;
    for l=1:length(date3)
        if date3(l,:)==k
            data2(ind,:)=data1(l,:);
            ind=ind+1;
        end
    end
end

data2;

[R1 C1]=size(data2)

\*Giving the miles information obtained from vissim*/
milesacc=0.3;
milesopp=0.1;
decacc=0.4;
decopp=0.3;
mt=data2(:,7);
Nt=data2(:,3);
St=data2(:,4);
rt=data2(:,5);
ct=data2(:,6);

\* Calculating the queue length */
for t=1:R1
    temp=data2;
mt1=mt(t,:);
ct2=ct(t,:);
for mt2=5:5:mt1
temp=data2;
qlengthacc=mt2*milesacc;
qlengthopp=mt2*milesopp;
Nt2=Nt(t,:);
St2=St(t,:);
Nt1=Nt(t,:)+qlengthacc;
St1=St(t,:)+qlengthopp;
rt1=rt(t,:);
temp(t,:)=[];
[R2 C2]=size(temp);
for t1=1:R2
rt2=temp(t1,5);
/* Boundary conditions*/
if rt2>=rt1 && rt2<=ct2
tsep1=temp(t1,:);
Nt3=tsep1(:,3);
St3=tsep1(:,4);
if (Nt3>=Nt2 && Nt3<=Nt1) || (St3>=St2 && St3<=St1)
tsep(ind2,:)=tsep1;
ind2=ind2+1;
end
der
end
tdecacc=(qlengthacc)/0.5;
tdecopp=(qlengthopp)/0.5;
ct1=ct(t,:)+tdecacc;
for wt=mt2:5:ct1
temp1=data2;
qlengthacc1=wt*milesacc;
qlengthopp1=wt*milesopp;
Nt8=Nt(t,:)-(wt*decacc);
St8=St(t,:)-(wt*decopp);
Nt9=Nt(t,:)+qlengthacc1;
St9=St(t,:)+qlengthopp1;
rt9=rt(t,:);
temp1(t,:)=[];
[R9 C9]=size(temp1);
for t9=1:R9
rt10=temp1(t9,5);
if rt10>=rt9 && rt10<=wt
tsep9=temp1(t9,:);
Nt10=tsep9(:,3);
St10 = tsep9(:,4);
if (Nt10 >= Nt8 && Nt10 <= Nt9) || (St10 >= St8 && St10 <= St9)
tsep10(ind21,:) = tsep9;
ind21 = ind21 + 1;
end
end
end
end
end
k = k + 1;
end
[R41 C41] = size(tsep)
[R51 C51] = size(tsep10)
date11 = tsep(:,1);
date21 = tsep10(:,1);
loc11 = tsep(:,2);
loc21 = tsep10(:,2);
N11 = tsep(:,3);
N21 = tsep10(:,3);
S11 = tsep(:,4);
S21 = tsep10(:,4);
for e = 1:R41
hr1(e,:) = fix((tsep(e,5))/60);
\[\text{mr1}(e,:) = \text{fix}(\text{rem}(tsep(e,5),60));\]
\[\text{hc1}(e,:) = \text{fix}((tsep(e,6))/60);\]
\[\text{mc1}(e,:) = \text{fix}(\text{rem}(tsep(e,6),60));\]
\[\text{hm1}(e,:) = \text{fix}((tsep(e,7))/60);\]
\[\text{mm1}(e,:) = \text{fix}(\text{rem}(tsep(e,7),60));\]
\]
\text{end}
\]
\text{final1}=[\text{date11} \ \text{loc11} \ \text{N11} \ \text{S11} \ \text{hr1} \ \text{mr1} \ \text{hc1} \ \text{mc1} \ \text{hm1} \ \text{mm1}];
\]
\text{[R10 C10]}=\text{size}(\text{final1})
\]
\text{for } e1=1:R51
\]
\text{hr11}(e1,:) = \text{fix}((tsep10(e1,5))/60);
\]
\text{mr11}(e1,:) = \text{fix}(\text{rem}(tsep10(e1,5),60));
\]
\text{hc11}(e1,:) = \text{fix}((tsep10(e1,6))/60);
\]
\text{mc11}(e1,:) = \text{fix}(\text{rem}(tsep10(e1,6),60));
\]
\text{hm11}(e1,:) = \text{fix}((tsep10(e1,7))/60);
\]
\text{mm11}(e1,:) = \text{fix}(\text{rem}(tsep10(e1,7),60));
\]
\text{end}
\]
\text{final2}=[\text{date21} \ \text{loc21} \ \text{N21} \ \text{S21} \ \text{hr11} \ \text{mr11} \ \text{hc11} \ \text{mc11} \ \text{hm11} \ \text{mm11}];
\]
\text{[R11 C11]}=\text{size}(\text{final2})
\]
\text{final}=[\text{final1};\text{final2}]
\]
\text{[R20 C20]}=\text{size}(\text{final})
\]
\text{ind10}=1;
\]
\text{for } s=1:R20
\]
\text{for } d=s+1:R20
count10=0;
for y=1:C20
    if final(s,y)==final(d,y)
        count10=count10+1;
    end
end
if count10==C20
    d1(ind10,:)=d;
    ind10=ind10+1;
end
end
end
final(d1,:)=[];
size(final)
/*Writing the results into an excel file*/
xlswrite('peakresults.xls',final)
rohitpart3
This program is utilizes the moderate file obtained in 'rohitpart1' as input. In this the rate
of increment and decrement of queue obtained from visism simulations are used.
Boundary conditions are calculated and applied to the data in this program. The output
file obtained in this part contains the secondary incidents occurred during moderate
traffic.
clc;
clear all;
close all;

\* Reading a file from the filtered data*/
data=xlsread(’moderate.xls’);
hr22=data(:,5);
mr22=data(:,6);
hc22=data(:,7);
mc22=data(:,8);
hm22=data(:,9);
mm22=data(:,10);
ind21=1;

\* Converting hours to minutes*/
for i=1:length(hm22)
    tr(i,:)=((hr22(i,:))*60)+mr22(i,:);
    tc(i,:)=((hc22(i,:))*60)+mc22(i,:);
    tm(i,:)=((hm22(i,:))*60)+mm22(i,:);
end

%fw=[15;95;215];
date=data(:,1);
loc=data(:,2);
N=data(:,3);
S=data(:,4);
main=[date loc N S tr tc tm];
ind1=1;

\* Filtering the data according to the location*/

for l1=1:length(loc)
    if loc(l1,:)==15
        data1(ind1,:)=main(l1,:);
        ind1=ind1+1;
    end
end

date3=data1(:,1);

ind2=1;

\* Separating the data according to the date*/

k=1;
for j=1:31
    ind=1;
    for l=1:length(date3)
        if date3(l,:)==k
            data2(ind,:)=data1(l,:);
            ind=ind+1;
        end
    end
end

data2;
[R1 C1]=size(data2)

/*Giving the miles information obtained from vissim*/
milesacc=0.3;
milesopp=0.1;
decacc=0.4;
decopp=0.3;
mt=data2(:,7);
Nt=data2(:,3);
St=data2(:,4);
rt=data2(:,5);
ct=data2(:,6);
/* Calculating the queue length */
for t=1:R1
    temp=data2;
    mt1=mt(t,:);
    ct2=ct(t,:);
    for mt2=5:5:mt1
        temp=data2;
        qlengthacc=mt2*milesacc;
        qlengthopp=mt2*milesopp;
        Nt2=Nt(t,:);
        St2=St(t,:);
        Nt1=Nt(t,:)+qlengthacc;
        Nt2=Nt2+qlengthopp;
\begin{verbatim}
St1=St(t,:)+qlengthopp;
rt1=rt(t,:);
temp(t,:)=[];
[R2 C2]=size(temp);
for t1=1:R2
    rt2=temp(t1,5);
    /* Boundary conditions*/
    if rt2>=rt1 && rt2<=ct2
        tsep1=temp(t1,:);
        Nt3=tsep1(:,3);
        St3=tsep1(:,4);
        if (Nt3>=Nt2 && Nt3<=Nt1) || (St3>=St2 && St3<=St1)
            tsep(ind2,:)=tsep1;
            ind2=ind2+1;
        end
    end
end
tdecacc=(qlengthacc)/0.5;
tdecopp=(qlengthopp)/0.5;
ct1=ct(t,:)+tdecacc;
for wt=mt2:5:ct1
    temp1=data2;
\end{verbatim}
qlengthacc1=wt*milesacc;
qlengthopp1=wt*milesopp;
Nt8=Nt(t,:)-(wt*decacc);
St8=St(t,:)-(wt*decopp);
Nt9=Nt(t,:)+qlengthacc1;
St9=St(t,:)+qlengthopp1;
rt9=rt(t,:);
temp1(t,:)=[ ];
[R9 C9]=size(temp1);
for t9=1:R9
  rt10=temp1(t9,5);
  if rt10>=rt9 & rt10<=wt
    tsep9=temp1(t9,:);
    Nt10=tsep9(:,3);
    St10=tsep9(:,4);
    if (Nt10>=Nt8 & Nt10<=Nt9) || (St10>=St8 & St10<=St9)
      tsep10(ind21,:)=tsep9;
      ind21=ind21+1;
    end
  end
end
end
k=k+1;
end

[R41 C41]=size(tsep)

[R51 C51]=size(tsep10)
date11=tsep(:,1);
date21=tsep10(:,1);
loc11=tsep(:,2);
loc21=tsep10(:,2);
N11=tsep(:,3);
N21=tsep10(:,3);
S11=tsep(:,4);
S21=tsep10(:,4);

for e=1:R41
hr1(e,:)=fix((tsep(e,5))/60);
mr1(e,:)=fix(rem(tsep(e,5),60));
hc1(e,:)=fix((tsep(e,6))/60);
mc1(e,:)=fix(rem(tsep(e,6),60));
hm1(e,:)=fix((tsep(e,7))/60);
mm1(e,:)=fix(rem(tsep(e,7),60));
end

final1=[date11 loc11 N11 S11 hr1 mr1 hc1 mc1 hm1 mm1];

[R10 C10]=size(final1)

for e1=1:R51
hr11(e1,:)=fix((tsep10(e1,5))/60);

mr11(e1,:)=fix(rem(tsep10(e1,5),60));

hc11(e1,:)=fix((tsep10(e1,6))/60);

mc11(e1,:)=fix(rem(tsep10(e1,6),60));

hm11(e1,:)=fix((tsep10(e1,7))/60);

mm11(e1,:)=fix(rem(tsep10(e1,7),60));

end

date21 loc21 N21 S21 hr11 mr11 hc11 mc11 hm11 mm11];

[R11 C11]=size(final2)

final=[final1;final2]

[R20 C20]=size(final)

ind10=1;

for s=1:R20

for d=s+1:R20

count10=0;

for y=1:C20

if final(s,y)==final(d,y)
count10=count10+1;

end

end

if count10==C20
d1(ind10,:)=d;
ind10 = ind10 + 1;
end
end
end
final(d1,:) = [];
size(final)
/* Writing the results into an excel file*/
xlswrite('moderateresults.xls', final)

rohitpart4

This program is utilizes the low file obtained in 'rohitpart1' as input. In this the rate of increment and decrement of queue obtained from visism simulations are used. Boundary conditions are calculated and applied to the data in this program. The output file obtained in this part contains the secondary incidents occurred during low traffic.

cle;
clear all;
close all;
/* Reading a file from the filtered data*/
data = xlsread('low.xls');
hr22 = data(:,5);
mr22 = data(:,6);
mc22 = data(:,8);

hc22 = data(:,7);
hm22 = data(:,9);
mm22 = data(:,10);

ind21 = 1;

/* Converting hours to minutes*/
for i = 1:length(hm22)
    tr(i,:) = ((hr22(i,:))*60) + mr22(i,:);
    tc(i,:) = ((hc22(i,:))*60) + mc22(i,:);
    tm(i,:) = ((hm22(i,:))*60) + mm22(i,:);
end

%fw = [15;95;215];
date = data(:,1);
loc = data(:,2);
N = data(:,3);
S = data(:,4);
main = [date loc N S tr tc tm];
ind1 = 1;

/* Filtering the data according to the location*/

for l1 = 1:length(loc)
    if loc(l1,:) == 15
        data1(ind1,:) = main(l1,:);
        ind1 = ind1 + 1;
    end
end
end

date3=data1(:,1);
ind2=1;

% Separating the data according to the date/
k=1;
for j=1:31
    ind=1;
    for l=1:length(date3)
        if date3(l,:)==k
            data2(ind,:)=data1(l,:);
            ind=ind+1;
        end
    end
end

data2;

[R1 C1]=size(data2)
% Giving the miles information obtained from vissim /
milesacc=0.3;
milesopp=0.1;
decacc=0.4;
decopp=0.3;
mt=data2(:,7);
Nt=data2(:,3);
\* Calculating the queue length */

for t=1:R1

temp=data2;

mt1=mt(t,:);

c2=ct(t,:);

for mt2=5:5:mt1

temp=data2;

qlen=mt2*milesacc;

qlenopp=mt2*milesopp;

Nt2=Nt(t,:);

St2=St(t,:);

Nt1=Nt(t,:)+qlen;

St1=St(t,:)+qlenopp;

rt1=rt(t,:);

temp(t,:)=[];

[R2 C2]=size(temp);

for t1=1:R2

rt2=temp(t1,5);

\* Boundary conditions*/

if rt2>=rt1 & rt2<=ct2
tsep1 = temp(t1,:);
Nt3 = tsep1(:,3);
St3 = tsep1(:,4);
if (Nt3 >= Nt2 && Nt3 <= Nt1) || (St3 >= St2 && St3 <= St1)
tsep(ind2,:) = tsep1;
ind2 = ind2 + 1;
end
end
end
tdecacc = (qlengthacc) / 0.5;
tdecopp = (qlengthopp) / 0.5;
ct1 = ct(t,:) + tdecacc;
for wt = mt2:5:ct1
  temp1 = data2;
  qlengthacc1 = wt * milesacc;
  qlengthopp1 = wt * milesopp;
  Nt8 = Nt(t,:) - (wt * decacc);
  St8 = St(t,:) - (wt * decopp);
  Nt9 = Nt(t,:) + qlengthacc1;
  St9 = St(t,:) + qlengthopp1;
  rt9 = rt(t,:);
  temp1(t,:) = [ ];
end
[R9 C9]=size(temp1);
for t9=1:R9
    rt10=temp1(t9,5);
    if rt10>=rt9 && rt10<=wt
        tsep9=temp1(t9,:);
        Nt10=tsep9(:,3);
        St10=tsep9(:,4);
        if (Nt10>=Nt8 && Nt10<=Nt9) || (St10>=St8 && St10<=St9)
            tsep10(ind21,:)=tsep9;
            ind21=ind21+1;
        end
    end
end

k=k+1;
end

[R41 C41]=size(tsep)
[R51 C51]=size(tsep10)
date11=tsep(:,1);
date21=tsep10(:,1);
loc11=tsep(:,2);
loc21=tsep10(:,2);
N11 = tsep(:,3);
N21 = tsep10(:,3);
S11 = tsep(:,4);
S21 = tsep10(:,4);

for e = 1:R41
    hr1(e,:) = fix((tsep(e,5))/60);
    mr1(e,:) = fix(rem(tsep(e,5),60));
    hc1(e,:) = fix((tsep(e,6))/60);
    mc1(e,:) = fix(rem(tsep(e,6),60));
    hm1(e,:) = fix((tsep(e,7))/60);
    mm1(e,:) = fix(rem(tsep(e,7),60));
end

final1 = [date11 loc11 N11 S11 hr1 mr1 hc1 mc1 hm1 mm1];

[R10 C10] = size(final1)

for e1 = 1:R51
    hr11(e1,:) = fix((tsep10(e1,5))/60);
    mr11(e1,:) = fix(rem(tsep10(e1,5),60));
    hc11(e1,:) = fix((tsep10(e1,6))/60);
    mc11(e1,:) = fix(rem(tsep10(e1,6),60));
    hm11(e1,:) = fix((tsep10(e1,7))/60);
    mm11(e1,:) = fix(rem(tsep10(e1,7),60));
end

final2 = [date21 loc21 N21 S21 hr11 mr11 hc11 mc11 hm11 mm11];
\[ \text{[R11 C11]} = \text{size(final2)} \]

\text{final} = \text{[final1;final2]} \]

\[ \text{[R20 C20]} = \text{size(final)} \]

\text{ind10} = 1; \]

\text{for} \ s = 1: \text{R20} \]

\text{for} \ d = s + 1: \text{R20} \]

\text{count10} = 0; \]

\text{for} \ y = 1: \text{C20} \]

\text{if} \ \text{final(s,y)} == \text{final(d,y)} \]

\text{count10} = \text{count10} + 1; \]

\text{end} \]

\text{end} \]

\text{if} \ \text{count10} == \text{C20} \]

\text{d1(ind10,:)} = d; \]

\text{ind10} = \text{ind10} + 1; \]

\text{end} \]

\text{end} \]

\text{end} \]

\text{final(d1,:)} = []; \]

\text{size(final)} \]

\text{\*Writing the results into an excel file*\} \]

\text{xlswrite('lowresults.xls',final)}
BIBLIOGRAPHY


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