

NDOT Research Report

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**Analysis, Modeling and Design for Traffic
Incident Management Systems**



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Analysis, Modeling and Design for Traffic Incident Management Systems

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Chapter 1

Executive Summary

1.1 Overview

Incident Management is an integral part of freeway and arterial traffic operations. It is designed to alleviate the problems associated with traffic incidents. Traffic incidents are non-recurring planned or accidental events that generally cause delay due to congestion as well as due to safety hazards. Planned events may be sports events, concerts, or else road maintenance or reconstruction projects. Accidental events include crashes, spills and disabled vehicles. Due to rapid growth in recent years, the Las Vegas region is now experiencing considerable congestion even outside the normal peak periods. An estimate of user costs for a one hour closure on highway I-15 in the peak direction during the afternoon peak hour is approximately \$240,000. This estimate does not include the traffic that would be caught in a queue that could propagate nearly 10 miles. The user cost of vehicles trapped at interchanges, including cross-street traffic, is not included nor is the cost of drivers who are rubber necking in the opposite direction. Finally, this user cost does not include the impact of the time needed for the traffic stream to recover once the closure is removed. This recovery time extends beyond the end of the peak period. The total cost could be three-fourths of a million dollars for a one hour closure. Overall, incidents result in the reduction of the operational efficiency of the transportation network, which leads to costly delays for the travelers, increased risk of secondary incidents, and safety risks to the incident responders.

The aim of incident management system is to minimize the total delay experienced by travelers and also to keep the whole operation safe. In order to achieve these two goals, the system should make optimal choices and use optimal designs. For the design of optimal solutions, appropriate mathematical models are needed for various tasks, and then mathematical techniques need to be developed. The mathematical models, their analyses and the creation of optimal solutions can help to create a framework for a decision support system for overall incident management. As an example, graph theoretic methods can be used with real-time traffic information to find out the best alternate route for traffic diversion after an incident. After an incident occurs, signal timings for signalized intersections or ramp meters also might have to be changed in order to respond to the transient traffic patterns. Since these patterns are non-recurring, the signals would have to be able to respond to real-time traffic demands so that traffic can be brought back to pre-incident levels in the minimum time possible.

1.1.1 Project Objective

The major aim of this project is to develop mathematical models, perform analyses, develop simulations, and then apply those to assist a decision support system for incident management in the Las Vegas area. In order to implement the system, this project 1) helps gain an understanding on current local practices in incident management, 2) evaluates alternate designs for incident management, and 3) designs a system that focuses on the details of field implementations and operations locally. This project involved the collaboration with various agencies in Clark County such as the Regional Transportation Commission (RTC) of Southern Nevada, the Nevada Department of Transportation (NDOT) and the Nevada Highway Patrol (NHP) through RTC's Freeway and Arterial System (FAST) as well as their consultant ITERIS, Inc. Additional collaboration also occurred with first responders of local agencies and the private towing industry.

1.1.2 Research Proposed

The following were the proposed tasks:

1. Identify the ITS infrastructure available for detecting the location of incidents and re-routing traffic
2. Evaluate public communications and education regarding incidents
3. Determine the availability of ITS elements for communicating to the public those locations where incident are more likely to occur
4. Obtain a system level mathematical model for the purposes of incident management; analyze the model, validate the model with data, and develop a simulation model. Perform studies with this simulation model.

1.1.3 Accomplishments

In addition to the proposed tasks, many topics had to be studied in order to encompass the broad topic of incident management. Listed below are the accomplished proposed as well as the additional tasks that were accomplished.

Accomplishments Corresponding to the Proposed Tasks

1. All available ITS methods of incident detection are identified by means of surveys, meetings, and collaborations with such agencies as FAST, NHP, and the Las Vegas Metropolitan Police Department (LVMPD).
2. Public communications strategies were determined by surveying agencies.
3. The availability of ITS for public communication is determined, and additional feasible solutions are proposed.
4. Mathematical models are developed, analyzed, and validated with data; models are developed for various aspects of incident management, such as secondary congestion, reliability, incident management process, and performance measures.

Additional Accomplishments

The following is the list of accomplishments in addition to the proposed tasks. This also presents the structure of the study as well as the report.

1. The incident management system is studied at multiple levels general, operational, technical, and theoretical
2. The general level involves:
 - (a) A literature review on the Incident Command System (ICS),
 - (b) Detailed information regarding the Traffic Incident Management Coalition,
 - (c) Summaries of meetings with various key emergency responders agencies, and
 - (d) Details and analysis of “before” and “after” survey details and analysis.
3. The operational level includes:
 - (a) Detailed information about modeling the incident management process,
 - (b) A proposed communications system that uses state of-the-art technology, and
 - (c) incident management stages details, such as current practices, challenges and limitations, public information dissemination evaluation, and recommendations.
4. The technical level includes:
 - (a) Crash data analysis and processing from LVMPD and NHP, and
 - (b) A proposed centralized and integrated database system that is currently under development.
5. The theoretical level includes:
 - (a) Formal modeling of incident management and software implementation,
 - (b) Secondary congestion modeling, a case study, and simulations,
 - (c) Construction and analysis of a Bayesian safety analyzer structure,
 - (d) various reliability measures, data analysis, and models, and
 - (e) Discussion and modeling of performance measures.

In this chapter, a summary of results and discussions for each chapter is presented. Please refer to the chapters for more details about each topic.

1.2 Incident Management- General

The ‘Incident Management- General’ section of this report, which includes Chapters 2 through 5, presents the main operational ideas behind the Incident Management System, and introduces the Incident Command System. This part also evaluates and presents information obtained from attending the TIM Coalition meetings as well as emergency responder meetings. Furthermore, this part considers a Pre-TIM survey and also presents the results of conducting an “after” TIM survey conduction.

1.2.1 Incident Command System (ICS)

The following is a list of actions that are suggested in the Federal Highway document, *The Simplified Guide to the Incident Command System for Transportation Professionals* (2):

- Communicate directly with incident management agencies in your jurisdiction. Look for ways where transportation stakeholders and these agencies can work more closely together.
- Encourage mutual-aid agreements among agencies with other agencies, for instance, those from bordering states, that might have key roles in major incidents.
- Constantly update existing mutual-aid agreements and verify that they reflect current responsibilities.
- Perform regular ICS training for your agency members involved in any aspect of the incident management.
- Develop or take a more active role in participating in your area's local preparedness organization focused on highway incident management.

1.2.2 Traffic Incident Management (TIM) Coalition

The Traffic Incident Management (TIM) Coalition is a program funded by the Nevada Department of Transportation (NDOT). One of the main goals of this program is to enhance communications among the different emergency responder agencies. In this coalition, representatives from different departments serve as members on the committee, which meets once a month. During each meeting, various subjects are discussed regarding incident management. These meetings allow the different agencies to communicate with each other their points of view and also to resolve misunderstandings by discussing the unique issues they are facing.

1.2.3 TIM Coalition Mission and Goals

Participating agencies include emergency responders from the City of Henderson, the City of Las Vegas, the City of North Las Vegas, and Clark County. The TIM program has gathered information from official documents and also has interviewed TIM Coalition members about the roles and responsibilities.

TIM identifies the following communication methods that are being used, as stated in the *Existing Conditions* document (7):

At the technical level, conduct communications by means of:

- Face-to-Face
- Remote Voice

- Electronic Text
- Other Media and Advanced Systems

At the operational level, communications can occur using:

- OpenSky 700 Megahertz (MHz)
- 800 MHz
- 150 VHF channel
- VHF
- Landline, phone or face-to-face interactions, and dispatch-to-dispatch communications

Throughout 2009, policies and procedures were revisited and these were finalized in March 2010. Currently, policies are limited by Las Vegas TIM boundaries, as defined by the southern Nevada TIM Coalition. The purpose of the policy placement, as stated in the *Traffic Incident Management Policies for Southern Nevada* document (9) is that: “regional policies for traffic incident management (TIM) model national ‘Best Practices’ involving multi-agencies and multi-discipline response to open roads/quick clearance (QC).”

A Joint Operations Policy Statement Agreement (JOPS) was developed by several emergency responder agencies in cooperation with two corporations, Delcan and Iteris, Inc. The agreement was signed on November 18, 2010 between the Nevada Department of Public Safety, Nevada Highway Patrol, and the Nevada Department of Transportation.

TIM Self Assessment

The TIM program has scored 71% in its 2010 self assessment, which was conducted by giving out a questionnaire designed to extract input from TIM members based on a number of strategic, tactical, and support criteria.

- The Strategic section of the assessment contributed 30% of the overall score. TIM scored 21%/30%.
- The Tactical section of the assessment contributed 40% of the overall score. TIM scored 30.8%/40%.
- The Support section of the assessment contributed 30% of the overall score. TIM scored 19%/30%.

1.2.4 Meeting with Emergency Responders

Throughout the project duration, multiple meetings were conducted with several agencies in order to qualitatively understand the incident management process from various points of view. Table 4.1 in Chapter 4, provides a list of the meetings that were attended.

The Freeway and Arterial System of Transportation- (FAST) Meetings Summary

The Freeway and Arterial System of Transportation, or FAST, is one of the first integrated Intelligent Transportation System (ITS) organizations in the country. It is a department of the Regional Transportation Commission (RTC) of Southern Nevada. FAST uses all available means and resources to perform traffic monitoring and control through infrastructure as well as data. **Traffic control** is accomplished through the use of traffic signals, ramp meters, dynamic message signs, and lane control signals. **Traffic monitoring** and detection of traffic conditions are required for proper traffic control. This is achieved through the use of video image detection and inductive loop detection. Visual verification of conditions is done through closed circuit television (CCTV) cameras. FAST uses all its resources in order to maintain the smooth operation of traffic.

Fire Department Meetings Summary

The Fire Department consists of professionally trained and specialized crews that are needed in many incidental cases. When the emergency number (911) is dialed, the call takers at the Public Safety Answering Point (PSAP) or LVMPD receive the call first, the caller is asked to choose between Fire, Medical, or Police. The Fire Department responds to both Fire and Medical. If the caller chooses either one, the call is transferred directly to the Fire Dispatch center. Thereafter, a unit is sent to the scene.

Las Vegas Metropolitan Police Department- (LVMPD) Meetings Summary

When a traffic accident occurs, the traffic division of the LVMPD becomes involved in the incident management process. LVMPD receives 90% of the 911 calls for all incidents, including burglary, fire, and crime.

There are three possible sources from where LVMPD can obtain information about a certain incident:

1. A direct call to Dispatch using the emergency number 911.
2. The incident was observed by an officer. In this case, the officer contacts the Dispatch Center by radio and gives all the details about the incident, for instance, car license plate number, location of incident, number of vehicles stopped, number of lanes blocked.
3. A direct call to the officer.

All the events are recorded in Computer Aided Dispatch (CAD) along with audio files. 90% to 95% of all information, such as time stamp and types of incident, is recorded in the CAD system. However, there is no direct link between crash reports and CAD data. The typical duration of LVMPD involvement for three types of traffic incidents, excluding the time that the agency took to reach the scene is as follows:

- PDO (property damage only) - 45 minutes
- Injury - 60-90 minutes
- Fatal - 4 hours

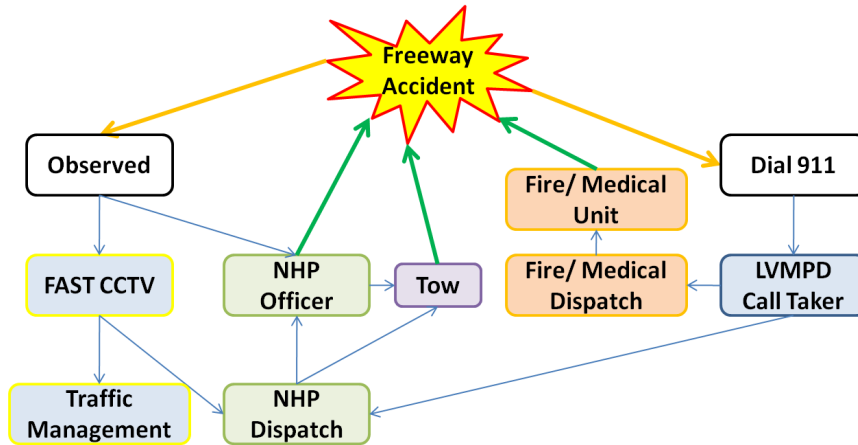


Figure 1.1: General model for freeway incident response

Nevada Highway Patrol- (NHP) Meetings Summary

Unlike LVMPD, NHP does not differentiate between a call taker and a dispatcher. In other words, the caller is also the dispatcher. NHP can be informed about an incident either by means of an emergency call transfer from LVMPD (911) or directly by means of FAST cameras; either way, NHP does not inform 911 of the occurrence of an accident. The NHP Dispatch Center and FAST operators share the same venue, working side by side to monitor the proper operation of the freeways. Therefore, NHP dispatchers have direct access to FAST cameras and can view the status of the freeway at all times. If they observe an accident in the video, they act immediately to clear it. In other cases, by using flow sensors the FAST software displays red at a particular location when an accident is suspected. Then, cameras are pointed towards that location in order to view the accident. If FAST cameras are not available, an NHP officer drives to the incident location. There are NHP Dispatch Centers at the following locations:

- Elko
- Carson City
- Las Vegas

Meetings Summary

Figure 1.1 shows the general model for freeway incident response. Figure 1.2 shows the general model for arterial incident response.

There are two ways to detect a freeway incident: by receiving an emergency call (911) or by observation. Emergency calls are received by call takers at the LVMPD Dispatch Center then forwarded to the NHP Dispatch Center, since freeways are in NHP's jurisdiction. NHP then obtains more information about the incident and communicates with other agencies, if needed. However, if the caller asked for Fire or Medical, then LVMPD call takers transfer the call to Fire Dispatch. With regards to detection by observation, there are two ways this can be accomplished: FAST CCTVs or NHP officer. In either case, the observer directly communicates with NHP Dispatch in order to properly manage the incident.

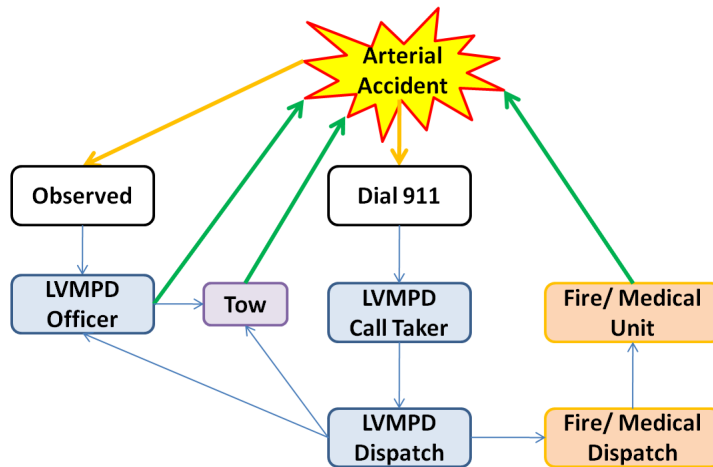


Figure 1.2: General model for arterial incident response

Similarly, an arterial incident also can be observed either by a 911 call or by observation. Observation, however, can only be done through an officer since FAST CCTVs currently do not cover arterial systems. In both cases, the incident is reported to LVMPD Dispatch, where incident verification is done in order to extract more information about the nature of the incident. LVMPD Dispatch determines what other agencies need to be dispatched to the scene as well such responders as Tow or Fire.

1.2.5 Survey

Chapter 5 mainly presents the “before” survey questionnaire regarding the effectiveness of TIM as well as the obtained results. An “after” survey was designed; however, the number of responses to this survey was not enough to conclude any significant results. The “after” survey can be found in the Appendix A. It is suggested that a more strategic, survey-based program assessment be conducted on a regular basis in future TIM programs.

“Before” Survey

Prior to the formation of TIM, the “before” survey was given to selected TIM members as an assessment of the Incident Management System in the Las Vegas area. The selection spanned personnel from several agencies Fire, Emergency Management (EM), the Coroner’s Office, the Regional Flood Center, the Freeway and Arterial System of Transportation (FAST), the Police Department (PD), the Nevada Department of Transportation (NDOT), Nevada Highway Patrol (NHP), and the Regional Transportation Commission (RTC). The sections of the survey are General, Incidents, Incident Response, Incident Management Legislation, Incident Technology and Equipment, Incident Management, Keeping Track of Incidents, and Incident Management Benefits. In this section, the survey questions are presented, followed by the results and conclusions.

Incident Definition

When agencies were asked to define incidents, most emergency responders defined them as

those events that need their services. Even though the answers seem to be similar, they contain a high degree of inconsistency because different agencies attend incident scenes under various circumstances. In addition, certain non-recurrent events are never reported. However, the answers clearly indicate that FAST, NDOT, and RTC consider any event that affects normal transportation operation as an incident. The definition that each agency gave directly reflects their operational responsibility. FAST, NHP, and RTC are more concerned with the overall “smooth” operation of the traffic system. However, the rest of the agencies are concerned about an incident only when they are involved.

Level of Involvement of Agencies

As shown in the graph in Figure 5.1 single vehicle crashes, disabled or abandoned vehicles, and multi-vehicle crashes have a high level of involvement from agencies. This indicates that coordination can become an issue in such scenarios. However, those types of incidents that do not have high agency participation must be studied through analysis of data specifically, response rate and clearance times.

Types of Secondary Incidents

According to most agencies, secondary incidents are normally either in the form of a collision or disabled vehicles. However, it is clear from Figure 5.2 that there is a great deal of inconsistency regarding what type of incident is more common. A proper data analysis must take place in order to accurately determine the different types of secondary incidents.

Collaboration among Agencies

Comprehensiveness as well as effectiveness of collaboration between agencies obtained similar rating on average. Both criteria averaged approximately a rating of 4 as depicted in Figure 5.3. However, it is not clear what every agency considered as effective or comprehensive.

Law Awareness

Figure 5.4 demonstrates the lack of awareness in laws related to traffic incidents. Agencies, especially law enforcement, must be clear on the status of relevant laws since that will provide them with confirmed actions to be executed on the incident scene. Furthermore, miscommunications among agencies are bound to occur due to such confusions. LVMPD has expressed that it does not support such laws since liability and insurance fraud issues can take place. Moreover, most agencies are not aware whether or not a legislation exists protects incident management responders from liability issues; some of them expressed that there is no such legislation.

Intelligent Transportation Systems (ITS)

As presented in the graph in Figure 5.5, the current incident management detection methods rely greatly on highway patrol communication, cellular phones, and traffic cameras. It is important to notice that traffic cameras and highway patrol coverage is restricted mainly on freeways. The arterial incident detection system relies heavily on cellular phones. The automated incident detection technology is not used, currently. The use of call boxes is not very common in the Las Vegas region.

Among all methods, cellular phones are consistently rated as one of the most used and efficient method for incidents detection, verification, and communications. This confirms

the need for the proposed Enhanced IM Communication and Data Collection System Using Smartphones as presented in Figure 6.3 in Chapter 6.

Regarding handling the incident management process, FAST and NDOT were the only agencies that filled this section out properly in the survey. At the time the survey was conducted, FAST, had already implemented traffic cameras, dynamic message signs, and a Traffic Management Center. Automated incident detection and automated vehicle locators were planned to be implemented. However, there was no discussion on implementing highway advisor radio or dynamic lane designation. At the time of the survey NDOT only had the highway advisory radio implemented, and had implementation plans for the rest of the listed technologies.

Equipment

The Fire Department, Henderson PD, and LVMPD filled out this part of the survey. Fire has indicated that they have the following equipment available a heavy duty truck, a sweeper, an empty box trailer, an air cushion recovery vehicle, a crane, a debris recovery vehicle, and a dump truck. Henderson PD and LVMPD indicated that their equipment mainly consisted of a heavy duty truck and a sweeper. NDOT, however, has all the above equipment available including an empty tanker truck, empty box trailer, and an empty live stock trailer.

Incident Management

Route Diversion: None of the agencies claimed that they have an alternate route plan except for RTC. It is crucial to realize the importance of alternate route plans which can contribute majorly to enhancing response times of all responding agencies, and therefore reducing incident clearance times.

Strategies: FAST, NDOT, and RTC were the only agencies that participated in the Strategies question. Notification through dynamic message signs and major equipment for vehicle removal were listed as incident management strategies that are currently used at FAST; however, route diversion is in the planning stages. NDOT has major equipment for vehicle removal and is in the planning process of implementing route diversion and notification through dynamic message signs. RTC uses multiple strategies, such as route diversion, notification through dynamic message signs, agreement with towing companies, and information sharing.

It was noted by some of the agencies that the lack of public awareness, lack of coordination among agencies, and lack of media understanding all contribute to problematic issues regarding strategies implementation.

Data

Many data that is collected by various agencies are not kept, specifically from phone calls, video recordings, and sensor readings. FAST and Regional Flood Control (RFC) keep sensor reading data for more than 90 days. Video recordings are kept more than 90 days by RFC, Henderson (HPD), and NHP. Phone calls are kept for more than 90 days by HDP and LVMPD. Please refer to the Results section of the survey for more detailed information about the kind of data each agency collects.

RFC and HPD both have expressed interest in having better access to FAST traffic cameras. The survey indicates that the data being collected by the agencies is not properly shared

among them. Most of these agencies can benefit greatly from much of this data. Clearly, a more technologically sound integrated database system as proposed in Chapter 8 is needed for the region in order to enhance efficiency as well as communications of the system.

Benefit and Cost Information Sharing

Sharing benefit and cost information with decision makers is mostly communicated by NDOT and RTC through personal, electronic, and print communications. Personal and electronics communications were rated as “4” in effectiveness, on a scale of 1 to 5 with "5" being most effective. However, print type of communications was given “3” rating. Information sharing with the public is done mostly through personal, electronic, and print communications as well as during public meetings. In all cases, effectiveness ranges between “3” and “4” on the ratings scale.

“After” Survey

This survey was designed at the final stages of the project with a very short time left for completion. Therefore, the response rate was not great enough to make any significant statistical conclusions. The survey is included in Appendix A as a reference for the reader.

1.3 Incident Management- Operational

On a broad level, the goals of an incident management system are to:

- Minimize the total delay experienced by travelers,
- Maintain or enhance on scene safety for other drivers and responders, and
- Use and share resources efficiently.

In this section, which includes Chapter 6, the performance of each stage of incident management will be discussed in terms of the above goals, considering available resources and current practices in the Las Vegas region.

1.3.1 Incident Management (IM) Modeling and Stages

Traditionally, only five incident management stages are recognized; however, in this study, an additional stage is recognized::

- **Stage 1:** Detection
- **Stage 2:** Verification
- **Stage 3:** Communication
 - Emergency Response
 - Motorist Information
- **Stage 4:** Management
 - Site Management
 - Traffic Management and Control
- **Stage 5:** Incident Clearance
- **Stage 6:** Congestion Clearance

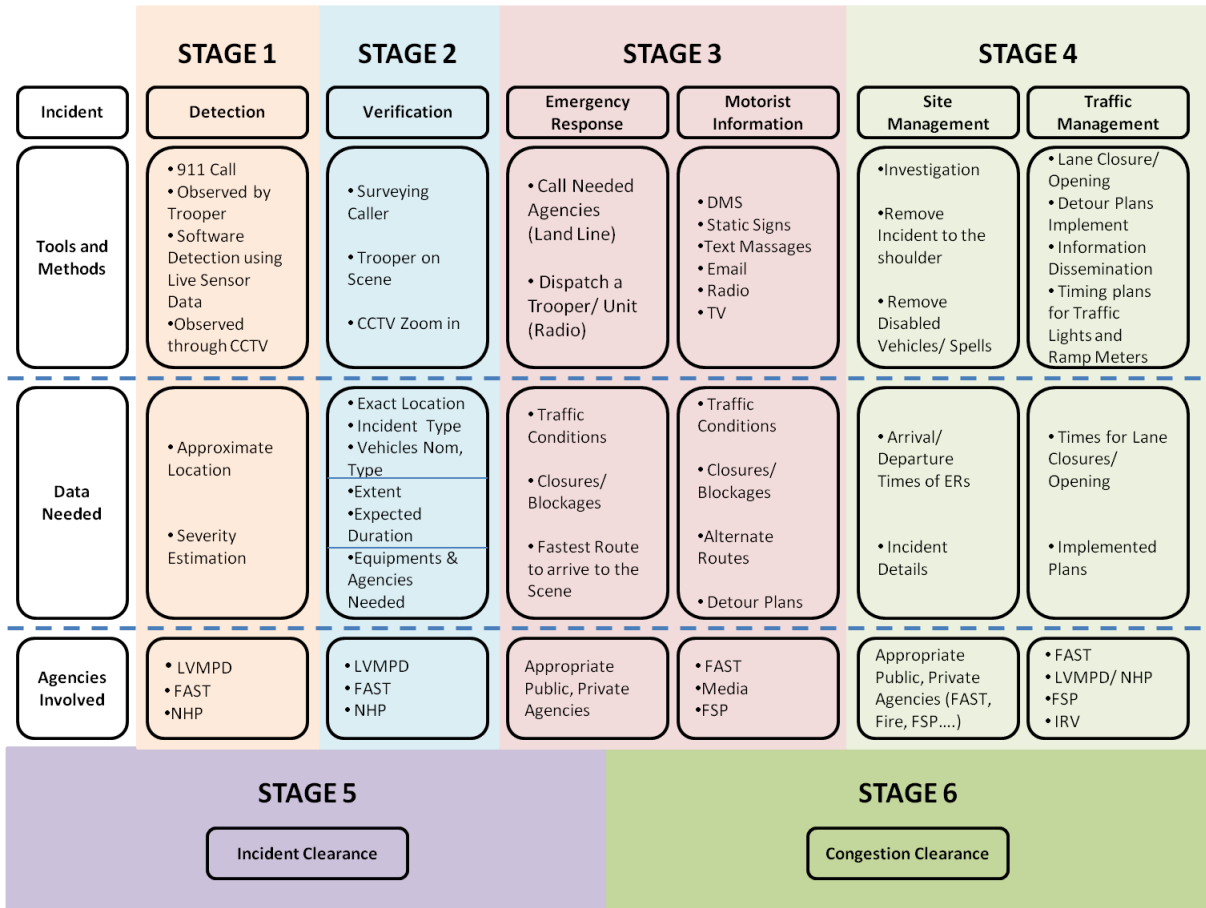


Figure 1.3: The incident management stages hierarchy

Incident Management Hierarchy

The identified stages of the incident management process are a mixture of sequential and parallel events. The hierarchy of the incident management stages is depicted in Figure 1.3.

Proposed IM Communication Model & ER Coordination in Las Vegas

Considering the existing resources, Figure 1.4 is the proposed communication and relational model for incident management in Las Vegas.

Proposed Enhanced IM Communication and Data Collection System Using Smartphones

Communications can be enhanced dramatically with the advanced technology available as shown in Figure 1.5. Smartphones are increasing exponentially in popularity. Furthermore, their flexible platforms and Software Development Kits (SDK) make them friendly devices for software developers, with a tremendous amount of applications specifically developed for transportation. In addition to the SDK, the developer software comes with a library that includes many built-in applications that can be used.

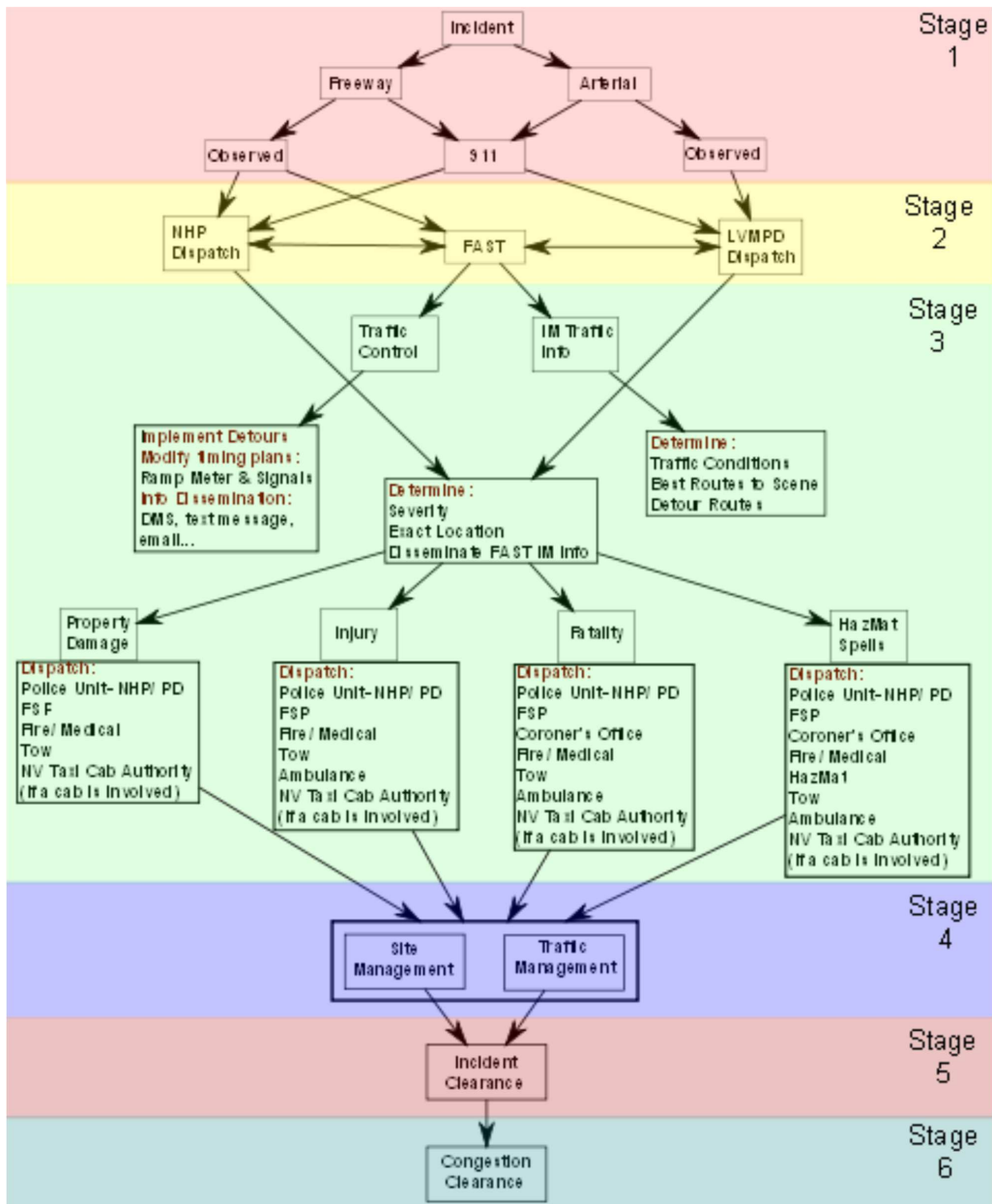


Figure 1.4: Proposed IM communication model

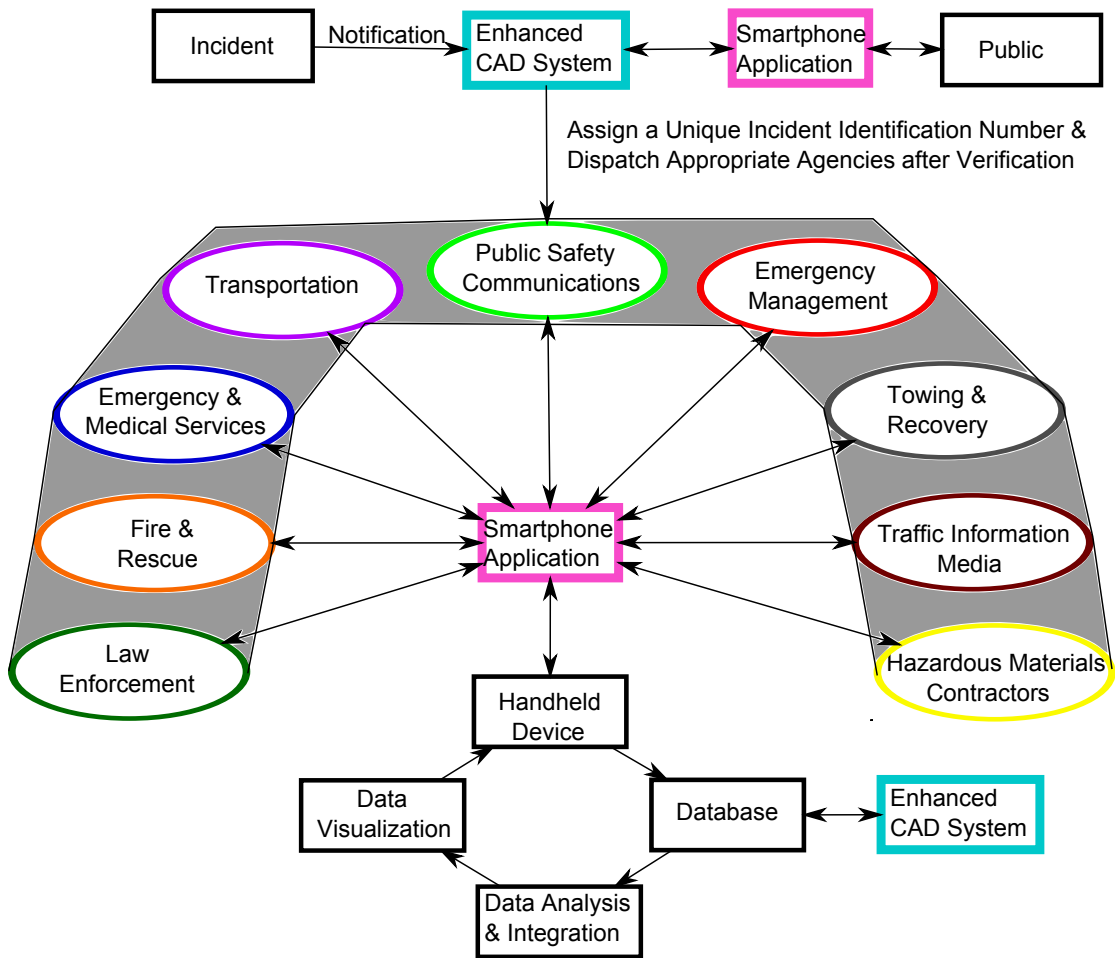


Figure 1.5: Enhanced IM communication and data collection system using smartphones

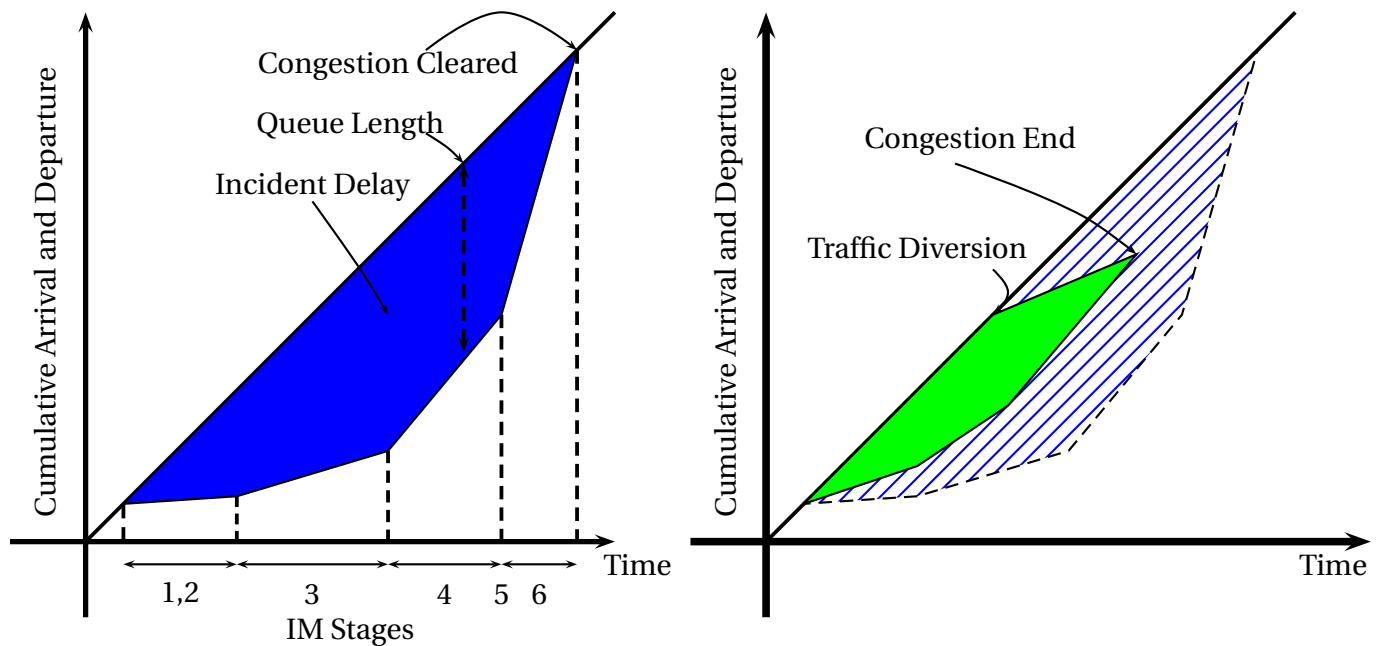


Figure 1.6: Incident management queuing delay model

Incident Management Queuing Delay Models

Figure 1.6 shows the overall effect of improving incident management on traffic congestion and delay caused by incidents.

Refer to Chapter 6 for more details about every stage of the incident management.

1.4 Incident Management- Technical

In this part of the report, which includes Chapters 7 and 8, crash data from multiple sources are analyzed and presented. Furthermore, a centralized and integrated database system is proposed, the Integrated Analysis and Visually Interactive Database (IAVID). Such a system is expected to increase efficiency and accuracy of data analysis by granting fast and easy access to a large amount of data as well as to resulting analyses. This system is currently being implemented at the Transportation Research Center (TRC) at UNLV.

1.4.1 Incident Management Related Data Analysis and Processing

The Transportation Research Center (TRC) at UNLV obtained freeway incident management data from NHP for a period of time that spans one year, from January 01, 2008 through June 30, 2009. NHP CAD data distinguishes between four types of incidents:

1. Fatality (referred to as 50F by NHP)
2. Property Damage (50P)

Table 1.1: Keywords

50F	NHP Code for Fatality
50P	NHP Code for Property Damage
50H	NHP Code for Hit and Run
50I	NHP Code for Injury
401	LVMPD Code for Accident
401B	LVMPD Code for Accident with Injury
UR	Unit Response Time
UA	Unit Arrival Time
ICA	Incident Clearance Time from Unit Arrival
ICC	Incident Clearance Time from Call Time
Jan	January
Feb	February
Mar	March
Apr	April
Jun	June
Jul	July
Aug	August
Sep	September
Oct	October
Nov	November
Dec	December
Ave	Average
St DV	Standard Deviation

3. Hit and Run (50H)

4. Injury (50I)

LVMPD CAD data was obtained for the period spanning seven years from 2003 through 2009. The data was first sorted according to two codes: 401 indicating an accident and 401B indicating an accident with injury. Three types of times were calculated for each code (code 401 and 401B):

- Unit response time (UR) = Unit arrival time - Time the event was reported
- Incident clearance time from the unit arrival (ICA) = Cleared time - Unit arrival time
- Incident clearance time (ICC) = Cleared time - Time the event was reported

NHP CAD Data General Analysis

The plot in Figure 1.7 displays the data for each month. On average, clearance of a fatality-related incident takes six hours with a **standard deviation of 0.045** indicating a significant

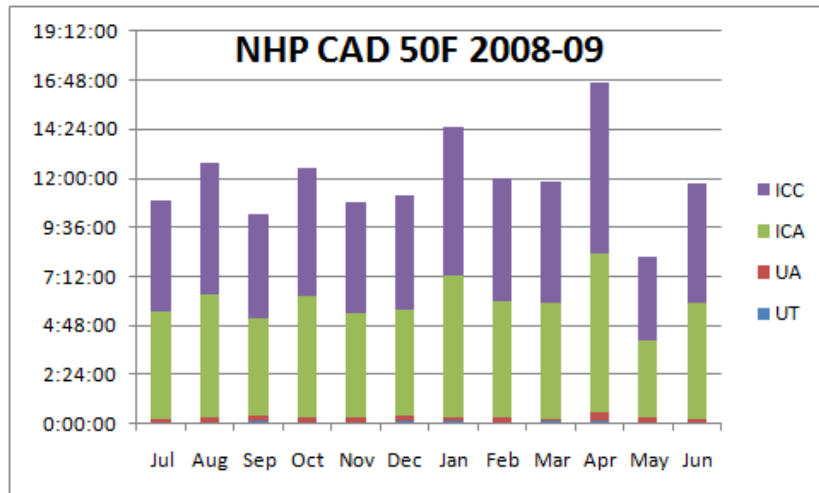


Figure 1.7: NHP CAD data analysis- Fatality

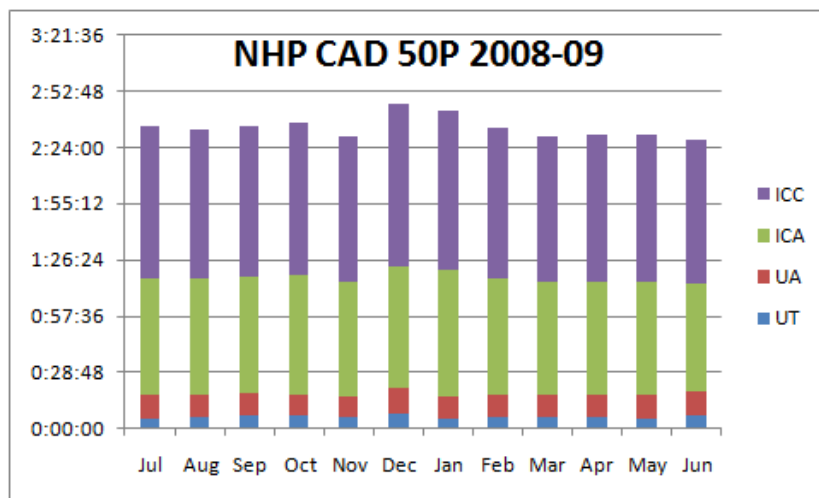


Figure 1.8: NHP CAD data analysis- Property Damage

degree of consistency in clearance times. It is noted from the graph in Figure 1.7 that a significant decline in clearance times occurred during May 2009; however, it went back to average during June. Therefore, no conclusions can be drawn regarding the improvement of the management process of fatality incident. In general, data has shown that the average unit arrival time is less than **15 minutes**. However, in some cases the unit arrival time can be **30 minutes** or more. The average unit response ranges between **4 to 9 minutes**, according to compiled data from all types of incidents.

The plot in Figure 1.8 displays the data for each month. On average, incidents that involve property damage take **one hour and 17 minutes** to clear with a great deal of consistency given that the standard deviation is calculated to be **0.001**. No significant improvement can be concluded.

More of an oscillatory pattern can be noted in property damage types of incidents as depicted in Figure 1.9. On average, this type of incident takes one hour and 13 minutes to clear. As depicted in Figure 1.10, the average clearance time for these kind of incidents are approximately **two hours**. Note that the difference between clearance times of incidents that involve injury and property damage versus hit and run incidents is 40 minutes, on average.

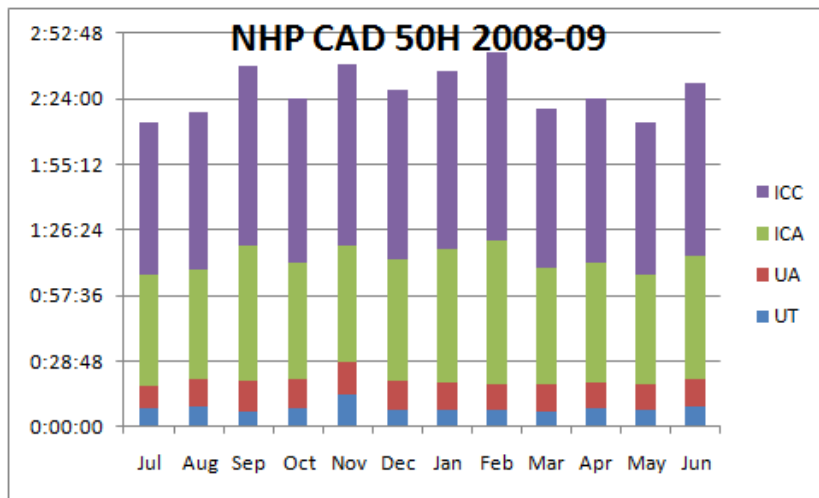


Figure 1.9: NHP CAD data analysis- Hit and Run

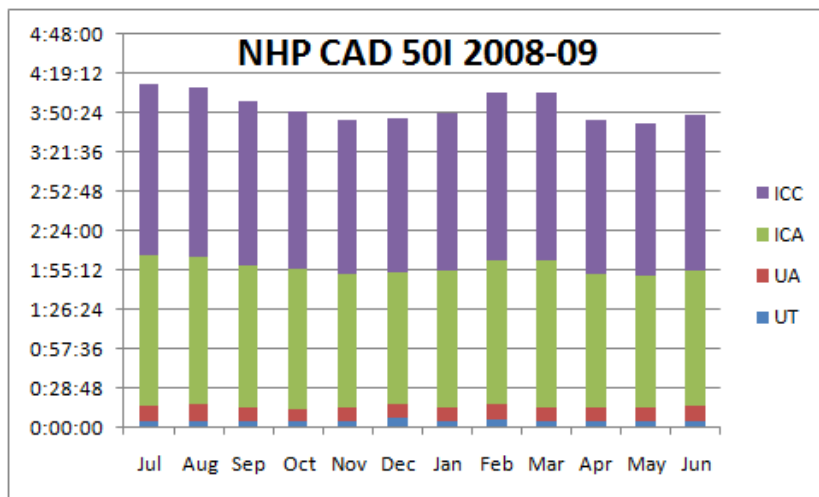


Figure 1.10: NHP CAD data analysis- Injury

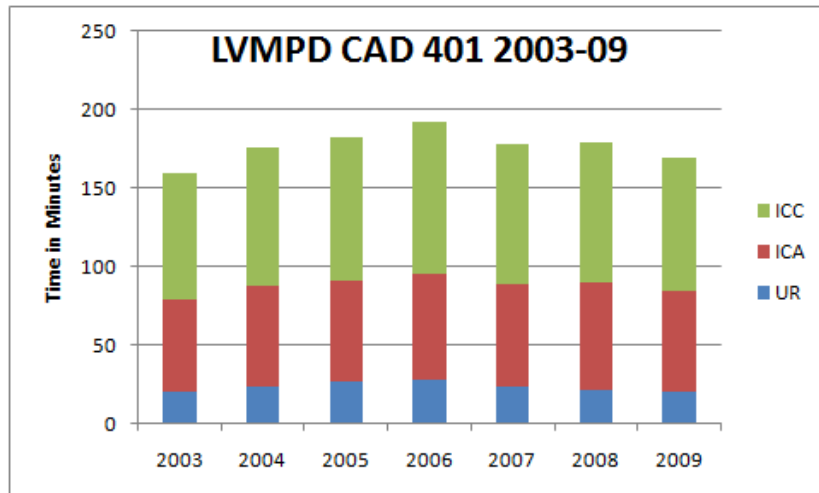


Figure 1.11: LVMPD CAD data analysis- 401

Secondary Incidents Analysis Using NHP Data

In order to estimate traffic related parameters, the least mean square estimation method was used to obtain the generalized relations. These relations give the estimates of peak, moderate and low traffic volumes from an average traffic volume. From the VISSIM simulation, the rate at which the queue length formed for the peak traffic volume in both directions is 220 and 100 miles/minute. The queue lengths that decreased in both directions by 410 and 350 miles/minute. As the queue gets cleared, the rate of movement of the distraction point is given as 410 miles/minute. Similarly, the rate at which the queue length formed for the moderate traffic volume in both directions is 163 and 77 miles/minute. The queue lengths decreased in both directions are 450 and 325 miles/minute. The rate of movement of the distraction point as the queue gets cleared is 450 miles/minute. The rate at which the queue length formed for low traffic volume in both directions is 65 and 30 miles/min. The queue lengths decreased in both directions by 50 and 220 miles/minute. The rate of movement of the distraction point as the queue gets cleared is given as 450 miles/minute. By applying the above conditions to the MATLAB code, the secondary incidents are identified to be **23%** of the total incidents; in addition, the **maximum number of secondary accidents occurred during mid-day.**

LVMPD Data Analysis

A general accident (401 type) takes approximately an **hour and 35 minutes** to clear. However, an accident involving injury takes about an **hour and 40 minutes** of clearance time. Note that in general, arterial incidents take longer to clear. Furthermore, it is noted that the average response time is 20 minutes. Plots in Figures 1.11 and 1.12 do not show any sort of improvement in clearance times over the years.

It was claimed that the incident management data obtained from NHP and LVMPD are not accurate in terms of incident clearance times since it is not clear exactly when the units logged out of the incidents.

In order to be able to draw more detailed conclusions on the performance of the incident management system, more thorough data is needed. TRC UNLV has initiated the design and

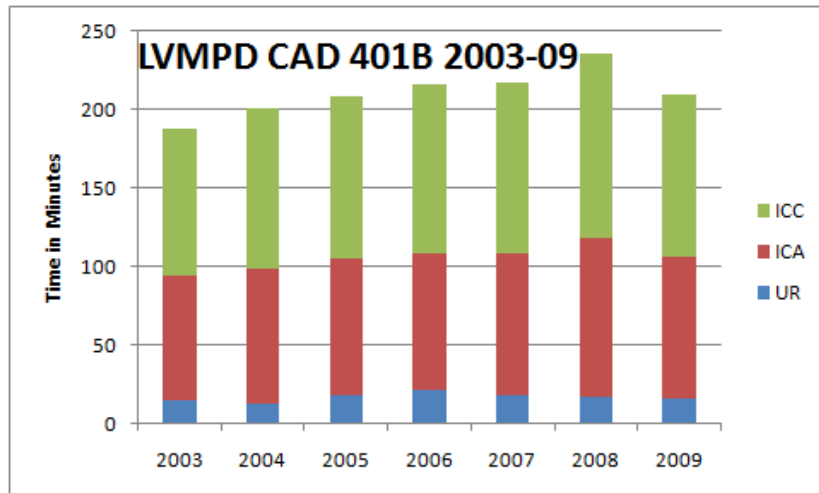


Figure 1.12: LVMPD CAD data analysis- 401B0

implementation of an integrated database that would serve this purpose (refer to Section 8). However, obtaining data is a challenging task. In order to resolve these issues, system enhancement tools as proposed in Section 6 can be easily integrated with an already integrated database.

1.4.2 Integrated Analysis and Visually Interactive Database (IAVID) for Transportation Systems

With the enormous increase in traffic demand, which is leading to the expansion of transportation networks and degradation in safety, the transportation system is becoming more complex. In the hopes of resolving a number of issues, transportation professionals and engineers have demonstrated interest in such aspects of transportation as safety, congestion, incidents, incident management, economic loss, drivers experience, reliability, performance measures, and resource allocation. Ultimately, decision making regarding all these operational level topics should be studied and analyzed. IAVID is a software system that efficiently performs a comprehensive data integration and analysis as demonstrated in Figure 1.13. The available data is of extremely high resolution, and this requires large databases. Also, this huge amount of data is not very useful in its raw form; therefore, a rigorous and strategic data analysis plan is required to be integrated with the real time data being collected. This integrated system will allow users to make the most out of the data that is being collected in real time by providing real time analysis and visualization. By providing statistically significant timely data and also by correlating causes and effects, a true understanding of the system is gained that enhances the decision-making process at many levels.

1.5 Incident Management- Theory and Application

In the 'Incident Management- Theory and Application' section, which includes Chapter 9 to 13, various theoretical aspects of the incident management are discussed, such as incident management process modeling, secondary congestion, safety analysis and data handling, reliability, and performance measures.

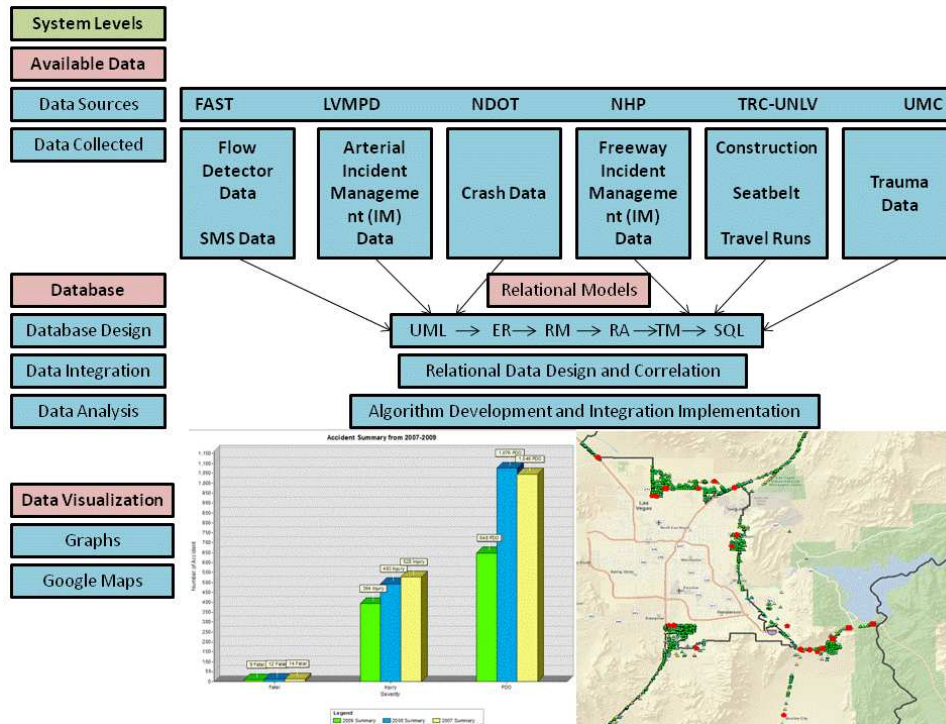


Figure 1.13: Integrated Analysis and Visually Interactive Database (IAVID) for Transportation Systems

1.5.1 Formal Language and Automata Theory Modeling of Incident Management

This study proposes the use of formal language and automata theory for modeling and analyzing the traffic incident management process. Incident management is a very practical discipline; however, theoretical modeling and analysis can help in finding inefficiencies in the system as well as improving it. Formal language and automata theory provides the foundation that has been used successfully in numerous hardware and software developments with applications in digital design, compilers, programming languages, etc. Every agency involved in the incident management process can be modeled as an individual processing unit that interacts with other units. Formal language and automata theory provide us with powerful tools for developing, analyzing, and debugging such models. Creating an incident management model with a systematic structure permits a methodical identification of the system's "bugs". Through a case study in the Las Vegas area and by using formal languages and automata theory, this study demonstrates the development of models of some first response incident management agencies. Sequence properties are checked for the developed models.

The purpose of formal languages theory is to bring order to complex system anarchy (43). Formal languages are characterized by predefined rules, such as formal notations in mathematics, logic, and computer science (10, 43). A finite automaton is a string processor that assists in defining certain formal languages by accepting or rejecting a sequence of symbols (43). Applications that require pattern recognition techniques have a fundamental interest in finite automata (10). A deterministic finite automaton consists of a finite number of states

or conditions in which a system can exist. Only one of these states can be an “initial” state. Additionally, such an automaton must contain at least one or more “terminal” or “accepting” states. Transitioning may be performed through two different actions, either by switching to another state or by remaining in the current state (10). Execution of state transition depends on the current state and the action identified by the symbol.

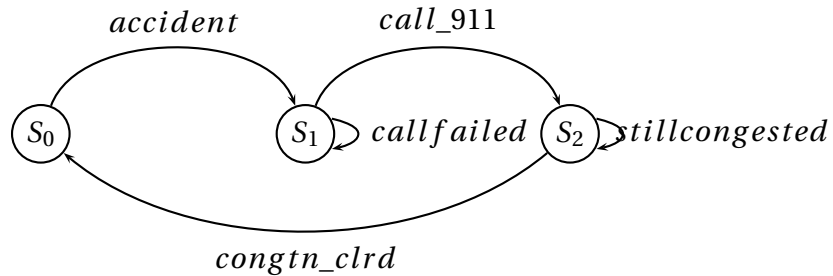


Figure 1.14: A simple state diagram based model for an incident occurrence

Using finite automata, a simple example of an incident may be modeled in a pictorial form called a state diagram, as depicted in 9.2.

Labeled Transition System Analyzer (LTSA) v3.0 and Modeling Software is used to construct Finite State Processes (FSP) and to perform property checking on developed models. This is a Java-based open source software. The exact algorithms as well as executions are given in this paper under Programs.

This study demonstrates incident management modeling using formal languages and automata theory. Formal languages methodology provides the ability to perform rigorous debugging and analysis through which robustness of the Incident Management system can be achieved upon implementation. This approach allows analysis to be conducted of processes concurrently executed processes that have specifications for liveness as well as safety properties specifications. The purpose of this approach is to model the traffic management processes in various coordinating agencies and then to find out if undesirable situations exist, such as “semaphores locking”. This method offers flexibility in modeling various Incident Management systems that account for many possible existing scenarios. Formal modeling can lead to the development of customized systems, resulting in a more successful Incident Management process. The approach studied in this study can be expanded to include a wider range of resources for every process within the agencies as well as to model additional agencies that might be involved in the Incident Management process. In addition, this model can be enhanced to include real-time information within the states representing traffic conditions or other continuous, random activities. Finally, real-time data and statistics can be incorporated to support predictions and estimations.

Formal methods, modeling provides practical and accessible techniques that aid evaluating designs for concurrent software. The incident management process is composed of a combination of sequential and concurrent events that are performed by multiple agencies. Therefore, it is inevitable that incident management software must feature high level of concurrency in its design. Formal methods are found to be very suitable and natural for incident management modeling, from which incident management software can be developed. Using formal methods modeling and its associated features, such as concurrency and property

checking, can provide flexible and appropriate tools for software design, leading to enhancement in communications, response, and management. From a practical point of view, formal methods modeling as well as associated software are used in order to ensure that the incident management process is well defined. The user - and in this case, the user can be any of the responder agencies, the Department of Transportation, or any party that has an active role in managing incidents - takes an active role in determining the structure of the model and defining the desired safety and liveness properties.

An approach based on formal methods is particularly useful for complex systems where high levels of hierarchy and concurrency are required. Complex models can be built based on modular structure. The software allows modular interaction through event sharing. This method is also useful when quantification of qualitative procedures is needed. For instance, the various Incident Management systems across the nation are evaluated based on the Incident Command. However, the Incident Command system stands as a document that is described qualitatively. This introduces challenges in achieving a common means of evaluation as well as a common structure among the different IM systems.

1.5.2 Secondary Congestion and Incidents

Incidents on urban freeways usually have a major impact on the normal operation of traffic, causing congestion and delays. What distinguishes incident related congestion from regular congestion is the speed differential. Incident related congestions lead to high differential speeds; this means that the vehicles change speeds abruptly, resulting in settings that are more prone to further incidents. With queues propagating rapidly, the probability of the occurrence of secondary incidents increases in the direction of the incident as well as in the opposing direction. Secondary incidents are of major concern, particularly for the incident management operations of the emergency responders. Emergency responders must adequately evaluate the operational implications of primary incidents for proper resource allocation and prevention of undesired expected or unexpected events. Only a few studies have been carried out to study secondary incidents. However, such studies have defined secondary incidents by means of progression curves that represent static, temporal, and spatial boundaries for the incident related congestion. Static progression is the least accurate for defining secondary incidents. In this study, progression curve models were studied and enhanced to cover the full range of operational effects of primary incidents. A case study in the Seattle, Washington region was used for a thorough study of freeway incidents as well as of the progression curves of the associated operational impacts. In addition, simulations from highway I-15 in Las Vegas were conducted to demonstrate a number of possible scenarios.

Figure 1.15 is the proposed model for identifying secondary incidents on freeways. Incident "A" in this figure can be identified by three curves: static, dynamic, and moving dynamic. Incident "B" can be identified only by the dynamic and moving dynamic methods. However, the dynamic approach will not be able to recognize incidents that take place within the secondary congestion, such as incident "C," or due to the rubbernecking effect, such as incident "E". Secondary incidents contribute to the increase of the queue length within which the occurrence of any incident can also be considered as secondary to the original incident, such as "D". Notice that the front of the queue in the rubbernecking region could vary with respect to the primary incident region. The area between the dashed line and the upper solid line

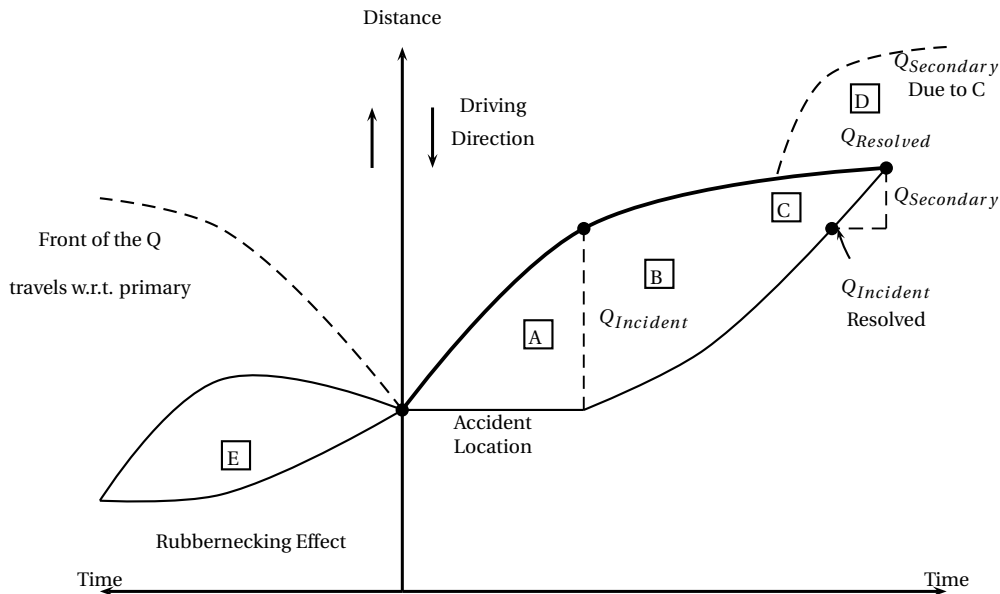


Figure 1.15: Proposed moving dynamic progression curve for incident related freeway congestions

in the rubbernecking region represents the range of possibilities for the front of the queue in Figure 10.9.

The full operational impacts of freeway incidents is analyzed through simulations as well as by means of a case study. In this section, the dynamic nature of incident-related congestions as well as secondary congestions are explored. It is found that depending on traffic conditions, congestion in the same direction of the incident may extend far beyond the queue formed during clearance time. In other words, the front of the queue propagates upstream, which leads to secondary congestion and increases the likelihood of secondary accidents. Moreover, an incident may cause distraction on a highway such as rubbernecking, which usually leads to the formation of another queue in the opposite direction of the primary incident. The congestion caused by this queue can have considerable delays, and increase the probability of secondary accidents in the opposite direction. As demonstrated in this study, the spatial and temporal range of the effects of a freeway incident effects often extend well beyond the static thresholds that have been used in the past for secondary incident investigations. Hopefully, this provides a strong motivation to initiate theoretical modeling so that the full implications of primary and secondary freeway incidents can be studied.

1.5.3 Bayesian Safety Analyzer

This study presents a very important tool in data integration, analysis, and probability theory. Bayesian theory is used in order to build a probabilistic data structure that can be used to extract likelihood information about various pieces of parameters that are updated through the enormous amount of data. A given data set usually has a number of attributes where the relationship between them is not well defined. When constructing a Bayesian structure over the available data set, each attribute becomes a node. The links between the nodes can be

determined by the nature of the problem, for instance bad weather conditions can impact the probability of incidents and therefore also of congestion. This leads to a nodal structure that has a topological order, where ancestor nodes must precede descendant nodes. The Bayesian Safety Analyzer (BSA) is designed based on an integration of multiple traffic and crash data sources. The BSA tool allows structuring the available data into a Bayesian Network. Based on the content of the data, the likelihood of different components occurring in the system can be extracted. Data for the BSA networks developed in this report is obtained from Freeway and Arterial System of Transportation (FAST), Nevada Highway Patrol (NHP), and Nevada Department of Transportation (NDOT).

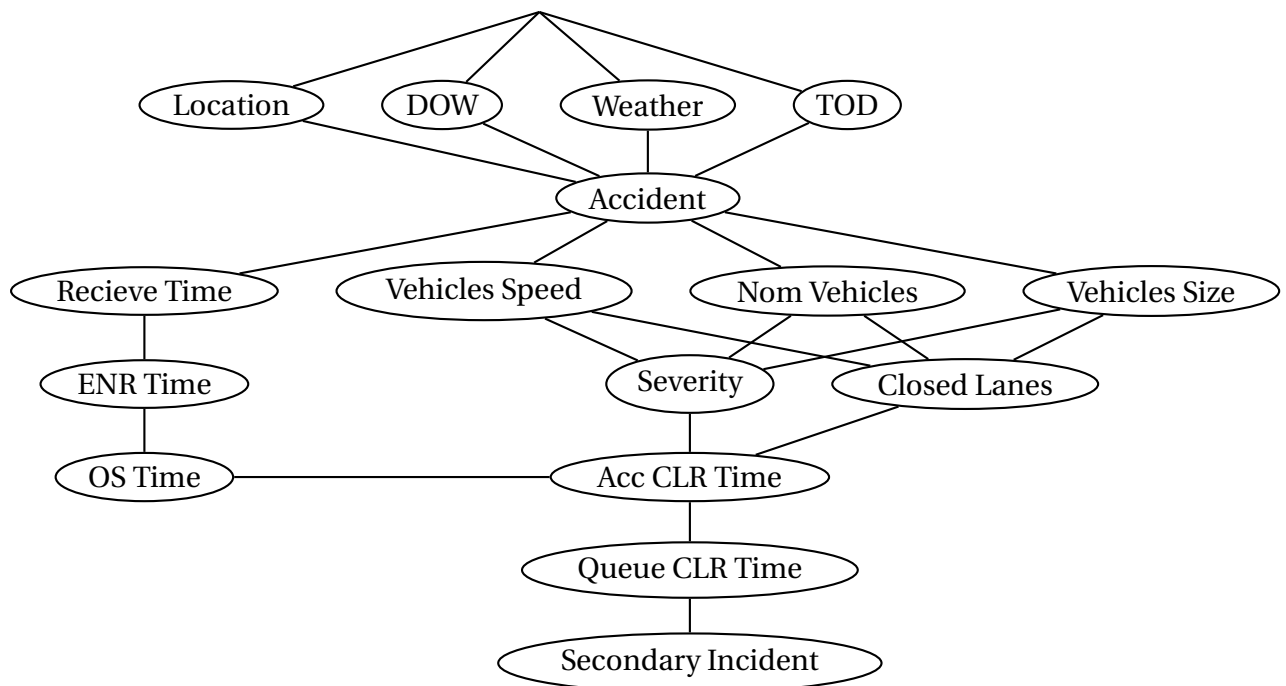


Figure 1.16: Proposed Bayesian Model

The Bayesian model in Figure 1.16 is formed by means of eight hierarchical levels. The increase of hierarchy level may reduce direct dependencies between parents' nodes and immediate children which implies simpler distribution tables for each node. However, the number of hierarchical levels is constrained by the nature of the problem being modeled since certain parameters directly depend on multiple parameters simultaneously.

In this study, a Bayesian Safety Analyzer (BSA) is constructed based on various data sources, mainly crash data and traffic data. It is demonstrated how posterior probabilities can be computed and how data can be used to train the Bayesian structure composed of a large amount of parameters. Bayesian analysis is proved to be a very efficient probabilistic method for analyzing a large set of data in order to better estimate dependencies and the likelihood of occurrence of various events.

1.5.4 Reliability Analysis

When evaluating the reliability of a route in terms of travel time, various quantitative measures are used, all of which differ to a certain degree in the information they contain. The

appropriate measure that ought to be chosen depends on the evaluation criteria. When defining reliability, most researchers as well as transportation entities use standard statistical methods. In this study, failure analysis approach is introduced in addition to the traditional reliability measures, travel time variance and confidence intervals. Moreover, an approach based on information theory is proposed, which adds a new dimension to the meaning of “reliability”. In order to demonstrate the differences and what each measure introduces, the proposed reliability measures are applied on travel time data obtained from Dynamic Message Signs (DMS) on the Interchange 15 (I-15) in Las Vegas. The term “reliability” suggests repeatability or dependability. For a random experiment this would mean that the results of an experiment are repeatable. In terms of travel-time, this would mean that if travel time is measured repeatedly on a section, comparable values can be obtained. In general, repeatability of travel time could be framed in terms of time-of-day, day of the week, etc. Thus, travel time reliability is determined by conducting analysis on data measured for a certain segment.

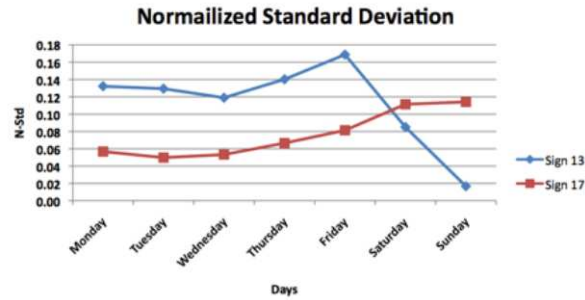
In this study five different approaches are used in obtaining various reliability measures:

- Classical Method: Planning Time, Planning Time Index, Buffer Index
- Variability, Based on Normalized Standard Deviation,
- Analysis of Variance ANOVA
- Travel Time Mean Estimation,
- Reliability as a Measure of Non-failures, and
- Information Theory Based Approach

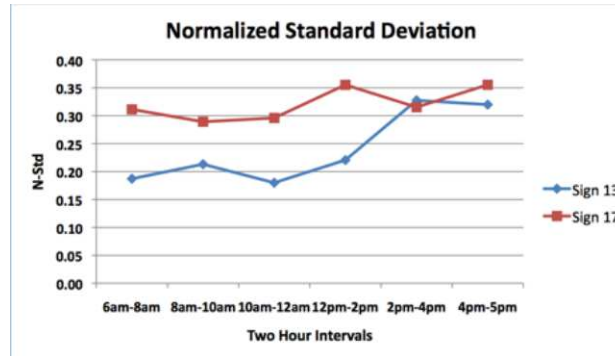
Figures 1.17(a) and 1.17(b) show the normalized standard deviation trends for Signs 13 and 17, located along the I-15 in Las Vegas.

The data was processed in two different ways: day to day and within the day. Day-to-day processing aggregates travel times for one day at a time, which allows comparison of aggregated travel times between different days of the week as well as weekends. In examining the obtained results for day-to-day analysis for Sign 13 in the northbound direction of the I-15, higher variability is noted during week days. However, lower overall NTSD was obtained for Sign 17 (I-15 southbound) compared to Sign 13. Results of the processed data during weekends show a higher variability for I-15 southbound (Sign 17) than for I-15 northbound (Sign 13). This phenomenon may be caused by the fact that drivers’ destination for that section of the freeway is most likely to be in the south direction during weekends since it leads to the center of the town. Overall reliability is not very high, which means that traffic conditions on that segment are somewhat inconsistent.

The F value obtained from the ANOVA hypothesis test with $\alpha = 0.05$. The F values obtained from the ANOVA analysis for both signs and the two types of analysis (day to day and within the day) are greater than the critical value F_{α} , which indicates rejection of the null hypothesis. These results show low consistency in travel times for the studied freeway section, thus, low reliability.



(a) Day to Day



(b) Within the Day

Figure 1.17: Normalized Standard Deviation Analysis

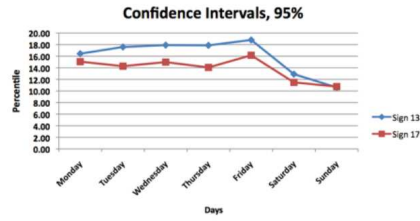
The 95th percentile for both signs is depicted in Figures 1.18(a) and 1.18(b). As expected, the 95th percentile averages approximately 18 and 14 minutes for Signs 13 and 17, respectively, during week days; however, they are much lower on the weekends. Analyzing “within the day” values, it is noticeable that travel times are much higher in the afternoon than they are in the mornings.

Figures 1.19(b) and 1.19(a) illustrate the trend for both “day to day” and “within the day” data. The following are the results obtained when non-failure analysis is used in determining reliability. Data was compared to an 11-minute threshold, based on a free flow speed of 65 mph as well as segment length that is approximately 10.5 and 7.7 miles for Signs 13 and 14, respectively. The results show a higher overall reliability for Sign 17 (southbound) than for Sign 13 (northbound). The data for the freeway section under study is unreliable for both directions in the afternoon as well as weekends. In this case, reliability indicates whether travel times are above or below the desired travel time.

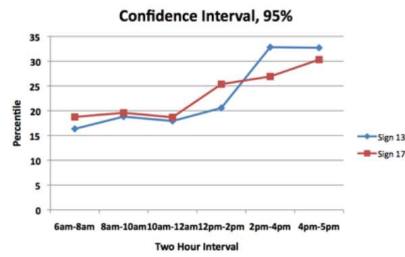
The reliability values obtained by using information theory are presented in Figures 1.20(a) and 1.20(b). Conducting the analysis using information theory, results have demonstrated consistency with the values obtained for NSTD, showing higher reliability and therefore lower variability for Sign 17 (southbound) compared to Sign 13 (northbound) during week days. A reversed effect is seen in the analysis of “within the day” data.

1.5.5 Performance Measures

Transportation systems are composed of many components that are highly networked. Components of the transportation system can be chosen based on the criteria of the system’s performance evaluation. For instance, a transportation system can be viewed as a network of

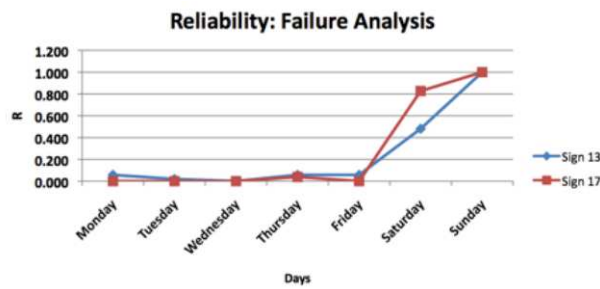


(a) Day to Day

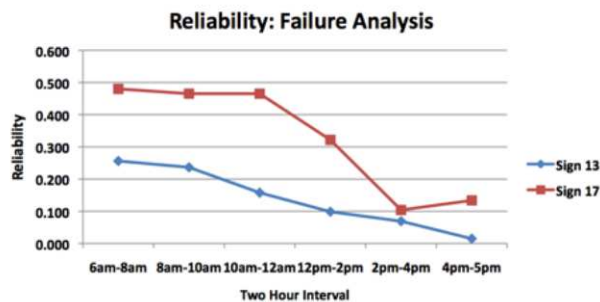


(b) Within the Day

Figure 1.18: The 95th percentile



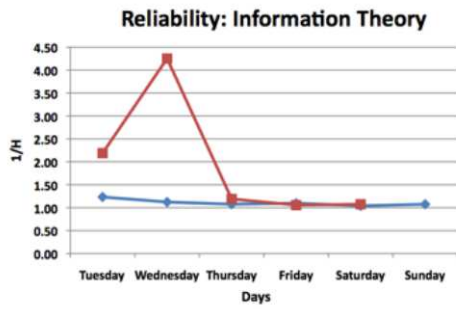
(a) Day to Day



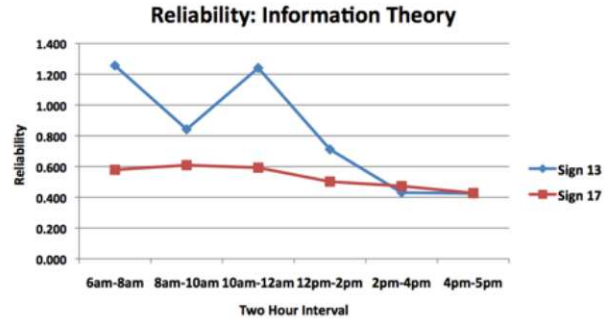
(b) Within the Day

Figure 1.19: Reliability as non-failure Analysis

the most common trip routes. One can also view the transportation system as a network of the seven inconsistency sources mentioned in the introduction (incidents, work zones, weather, fluctuations in demand, special events, traffic control, and inadequate capacity). In either case, a proper reliability measure must be developed for each component. Once developed, a Network Structure Map (NSM) can be developed based on the network's actual topology, in which the overall reliability of the transportation system can be measured.



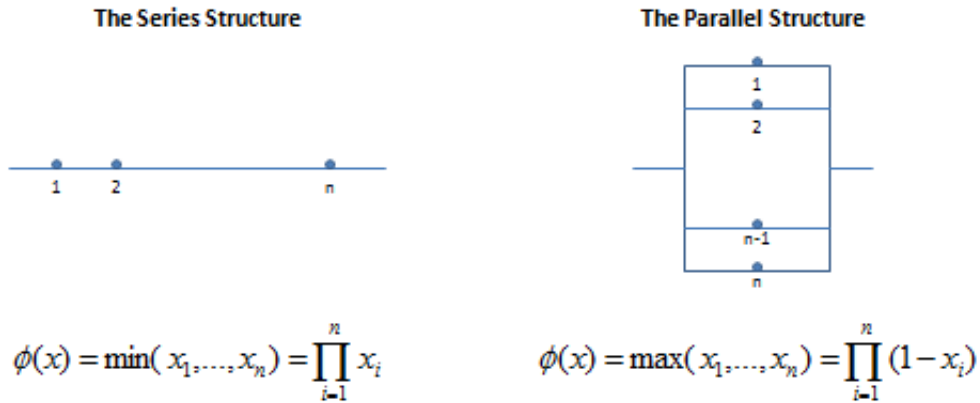
(a) Day to Day



(b) Within the Day

Figure 1.20: Information theory based reliability

It is evident that the operation of some components is essential for the operation of other components. Therefore, components of the transportation network may have two possible connections: A series connection or a parallel connection. Two components are connected in series if the operation of one depends on the operation of the other; parallel connections take place when the operation of one component is totally independent of the operation of the other one. Network Structure Functions (NSF) and NSM are depicted and illustrated in Figure 1.21 (45).



Where:

$x = (x_1, \dots, x_n)$ is the state vector.

$x_i = \begin{cases} 1, & \text{if the } i\text{th component is functioning} \\ 0, & \text{if the } i\text{th component has failed} \end{cases}$

$\phi(x) = \begin{cases} 1, & \text{if the } i\text{th component is functioning when the state vector is } x \\ 0, & \text{if the } i\text{th component has failed when the state vector is } x \end{cases}$

Figure 1.21: Network Reliability

Classical reliability definition and measures were studied and discussed Chapter 12. The classical definition was not consistent with the developed measures. Also, classical reliability measures are not consistent with each other, do not well represent consistency, and do not

address the overall performance measure of the transportation system. These three issues were targeted in this study. In addition, a modified definition inspired by manufacturing was introduced. A reliability measure based on information theory also was introduced and was shown to measure inconsistency more accurately than standard deviation. Finally, a network reliability measure was introduced.

1.6 Recommendations

1.6.1 Incident Command Structure

Federal Highway recommends transportation agencies to perform the following tasks as mentioned in *the Simplified Guide to the Incident Command System for Transportation Professionals*(2):

- Communicate directly with incident management agencies in your jurisdiction. Look for ways where transportation stakeholders and these agencies can work more closely together.
- Encourage mutual-aid agreements among agencies with other agencies (for instance, those from bordering states) that might have key roles in major incidents.
- Update existing mutual-aid agreements constantly and verify that they reflect current responsibilities.
- Perform regular ICS training for your agency members involved in any aspect of the incident management.
- Develop or take a more active role in participating in your area's local preparedness organization focused on highway incident management.

1.6.2 Traffic Incident Management (TIM) Coalition

It is recommended that the TIM coalition adopts a more structured strategy that is established with correspondence to the traffic incident management needs and issues of the specific region. The strategic plan establishment can be based on the following:

- Determine what areas in the traffic incident management need to be improved. This can be determined based on surveys, meetings, and available data
- Set specific goals for each area
- Develop practical and efficient strategies to reach the specified goals addressing the issues in each area.
- Specify mile-stones in the plan implementation
- Involve participating agencies and their representative members in the TIM coalition through

- Strategic training that can be performed by the TIM member to their agencies
- Policy awareness
- Information dissemination, and
- Development of Incident command system strategies
- Monitoring the various aspects of performance by means of
 - Surveys: before, during, and after survey design
 - Relevant data collection from participating agencies
 - Periodic data analysis, and
 - Quantification of goals and contributing factors
- Enhance the TIM plan as well as its implementation based on the performance monitoring results.

1.6.3 Performance Measures

It is crucial to quantitatively measure the performance of the transportation system in Las Vegas, specifically the Incident Management System. Such a measure would pinpoint pros and cons of common practices. Furthermore, a well designed performance measure will assist in isolating the sources of inefficiencies in the studied transportation system. In order to accomplish the mentioned goals, several main actions were identified as necessary. First, conducting a comprehensive study of the various CAD systems currently used among the different emergency responders in Las Vegas will be essential in order to understand the interaction, capabilities, constraints, and data availability of the system. Second, the development of performance measures has to be based on understanding the nature of the transportation system and conducting a comprehensive literature survey on performance measures that considers state-of-the-art research. Finally, data requirements must be customized, complying with the performance measures developed and compared to the available data based on which a CAD system enhancement plan will be developed, tested, and deployed.

1.6.4 Intelligent Transportation Systems

As demonstrated in, Subsections [1.3.1](#), [1.3.1](#), and [1.4.2](#), there are vast opportunities in using state-of-the-art technology to effectively enhance the operations of the current Incident Management System. The following are the main areas that require attention:

- Development, analysis, and visualization of integrated database, as demonstrated in [Figure 1.13](#).
- Enhancement of the communication and data collection system, as depicted in [Figure 1.5](#)

Part I

Incident Management - General

Chapter 2

Incident Command System (ICS)

2.1 What is the Incident Command System (ICS)?

2.1.1 Definition

According to *The Simplified Guide to the Incident Command System for Transportation Professionals* and Latoski:

“The ICS is a systematic tool used for the command, control, and coordination of an emergency response. ICS allows agencies to work together using common terminology and operating procedures for controlling personnel, facilities, equipment, and communications at a single incident scene” (2).

2.1.2 When is ICS Needed

As the incident size and complexity increase, the number of on-scene agencies needed to manage an incident increases. As a result, an ICS structure is required in order to efficiently coordinate between multiple responders from the different agencies.

2.1.3 Unified Command

The **Command** function is the requirement that an individual or several individuals maintain authority over all incident activities. The **Incident Commander (IC)** is a single person performing the command function. However, in major incidents, multiple personnel are needed to perform the command function. When more than one person is involved, then it is called the **Unified Command (UC)** (2).

2.1.4 Functional Structure

The National Incident Management System (NIMS) specifies the functional structure for the ICS, as stated in *The Simplified Guide to the Incident Command System for Transportation Professionals* (2). The ICS organization consists of six functions:

1. **Command** provides on-scene management and control authority.
2. **Operations** directs tactical operations of the incident.
3. **Planning** prepares an Incident Action Plan and also maintains situation and resources status.
4. **Logistics** provides services and support for the incident.
5. **Finance and Administration** incident costs and accounts for reimbursements.
6. **Intelligence** provides analysis as well as shares information and intelligence during the incident.

2.1.5 Conclusion

“ICS helps eliminate ambiguity in command and control, improves resource coordination and communications, and facilitates the application of standard guidelines and procedures in day-to-day highway incident management” (2).

The following is a list of actions that are suggested in the Federal Highway document, *The Simplified Guide to the Incident Command System for Transportation Professionals*(2):

- Communicate directly with incident management agencies in your jurisdiction. Look for ways where transportation stakeholders and these agencies can work more closely together.
- Encourage mutual-aid agreements among agencies with other agencies (for instance, those from bordering states) that might have key roles in major incidents.
- Update existing mutual-aid agreements constantly and verify that they reflect current responsibilities.
- Perform regular ICS training for your agency members involved in any aspect of the incident management.
- Develop or take a more active role in participating in your area’s local preparedness organization focused on highway incident management.

Chapter 3

Traffic Incident Management (TIM) Coalition

3.1 What is TIM?

3.1.1 Background

In September 2007, the Nevada Department of Transportation (NDOT), in partnership with the Federal Highway Administration (FHWA), invited first responder agencies involved in traffic incident management to participate in a two-day incident management workshop at the National Highway Institute, in Arlington, Virginia. The workshop served as a stepping stone towards initiating the development of a local traffic incident management (TIM) team of stakeholders who meet regularly and discuss regional issues involving traffic incidents (7).

3.1.2 TIM Coalition and Steering Committee

TIM is a program funded by the Nevada Department of Transportation (NDOT). One of the main goals of this program is to enhance communications among the different emergency responder agencies. In this coalition, representatives from different departments serve as members on the committee and meet once a month. During each meeting, various subjects are discussed regarding incident management. These meetings allow the different agencies to communicate with each other their points of view and also to resolve misunderstandings by discussing the unique issues they are facing.

3.1.3 TIM Coalition Mission and Goals

According to the *Traffic Incident Management Policies for Southern Nevada*

“Coordinate and sustain an effective multi-agency, multi-disciplinary and multi-jurisdictional TIM program that improves safety for responders and motorists and reduces traveler delay in the Las Vegas region of Southern Nevada” (9).

TIM Coalition's main goal is to build regional consensus at all levels of traffic incident management. Clearance times, HAZMAT removal, technology improvements, data collection, communications, agreements regarding performance measures, and recommendations are developed for a regional traffic incident management program that includes all first responding emergency and traffic agencies (7).

The following are the goals of TIM, listed in the *Existing Conditions* document (7):

1. Enhance the coordination, cooperation, and communications of responding agencies during traffic incident management.
2. Reduce the number and severity rate of traffic incidents on freeways in the Las Vegas region, and also increase safety at the scene.
3. Improve technology and the use of technology for traffic incident management and traffic congestion.
4. Improve consistency, accuracy, and timeliness of traffic incident management as well as congestion information to the public.
5. Increase funding, such as grants, and utilize available resources in the region to facilitate meeting goals and objectives for traffic incident management.

3.1.4 Participating Agencies

The following is a list of participating agencies from the City of Henderson, the City of Las Vegas, the City of North Las Vegas, and Clark County:

- Police Department(PD)
- Public Works
- Fire Department
- Coroner's Office
- Maintenance and Operations
- Department of Public Safety: Emergency Management (EM) and Nevada Highway Patrol (NHP)
- Towing: Ewing Brothers, Quality Towing, and North Star Towing
- The Freeway and Arterial System of Transportation (FAST)
- Federal Highway Administration
- Las Vegas Metropolitan Police Department (LVMPD)
- Nevada Department of Transportation (NDOT)

- Nevada Transportation Authority (TSA)
- National Park Service (NPS) Ranger Activities Division
- Regional Flood Control
- Regional Transportation Commission (RTC)
- Stewart Environmental Consultants
- Iteris, Inc.
- Delcan Corporation
- Transportation Research Center (TRC) University of Nevada Las Vegas (UNLV)

3.2 Roles and Responsibilities of Emergency Responders by TIM

TIM program has gathered information from official documents and also interviewed TIM Coalition members about the roles and responsibilities. This section presents the result of this process, which was also presented in the *Technical Memorandum Existing Conditions, Mission Goals, and Objectives* document (7).

3.2.1 Federal Agencies

The Federal Highway Administration:

- aids in operations of highways and sets standards,
- publishes “best practices” for traffic incident management and provides planning guides,
- provides training options for partners involved in traffic incident management.

The Federal Emergency Management Administration (FEMA):

- manages national emergencies and hazards,
- provides federal response and recovery efforts,
- initiates proactive mitigation activities,
- trains first responders, and
- manages the National Flood Insurance Police and the U.S. Fire Administration.

3.2.2 State Agencies

The Department of Safety - Nevada Highway Patrol(NHP):

- receives 911 calls that are forwarded from the Public Safety Answering Point (PSAP);
- serves as Incident Command for most incidents on the freeway/highway for the Las Vegas region as it is responsible for managing the incident, traffic diversions, clearance of the roadway, and investigation of crash scenes on state highways and interstate freeways;
- interacts with all emergency agencies and public information media regarding incidents, maintains dispatcher availability;
- posts Dynamic Message Sign (DMS) messages and monitors Closed Circuit Television (CCTV) video feeds displayed on the video wall when FAST employees are not available;
- uses a Computer Aided Dispatch (CAD) system to locate and manage incident information (this system cannot currently communicate directly with other agencies systems);
- communicates with other agencies by means of individual agency dispatchers;
- contacts Coroner in fatality cases. and
- provides security oversight of NHP and Regional Transportation Commission (RTC) FAST Traffic Management Center (TMC).

The NHP maintains a secure information system which is inaccessible by other agencies, communicating primarily by means of radios and cell phone. It uses dedicated 800 MHz radio for interagency communications but also has access to County's new 700MHz system.

The Nevada Department of Transportation - District 1 (NDOT District 1):

- provides a maintenance staff that assists in traffic control, cleaning up debris, managing HAZMAT cleanup, and repairing the roadway;
- receives incident feedback from NHP;
- operates and maintains four Highway Advisory Radios (HAR) in Southern Nevada;
- works with NHP and other regional emergency responders to provide 511 information about the region's traffic status for the future statewide 511 system; and
- manages FAST agreements as well as provides funding for Traffic Management Center (TMC) Facilities Management.

Nevada Department of Transportation - Headquarters (NDOT HQ):

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

The Freeway Service Patrol:

- assists motorists who need roadside assistance,
- assists in providing safety for drivers and the individuals at incident scenes,
- assists NHP with traffic control in order to prevent secondary incidents, and
- assists in the rapid removal of vehicles and debris from travel lanes and paved shoulders.

The Nevada Department of Transportation Communications Department:

- manages and oversees State NDOT radio systems,
- oversees the Statewide Communications Committee, and
- assists in integrating of communications systems when required.

3.2.3 Local Agencies

The Las Vegas Metropolitan Police Department (MPD):

- serves as the Public Safety Answering Point (PSAP) in taking 911 calls;
- shares responsibility with NHP for managing incidents on County roads, managing traffic diversions, and managing the clearance of roadways;
- interacts with all emergency agencies and public information media regarding incidents;
- communicates with other agencies by means of individual agency dispatchers;
- owns and operates a 700MHz communications system.

The North Las Vegas Police Department (NLVPD):

- serves as the Public Safety Answering Point (PSAP) in taking 911 calls;
- forwards 911 calls to NHP when contacted by travelers regarding freeway/ highway incidents;
- operates AIMS system for traffic incident management on corridors in the NLVPD area;
- manages traffic for the Las Vegas Speedway;
- communicates with other first response agencies via individual dispatchers; and
- responds to calls for traffic incident management.

The Clark County Environmental and Risk Management Agencies

- communicates with NHP during incidents that involve large commercial vehicles; and
- manages HAZMAT contracts for clearance of HAZMAT spills and/or removal of commercial vehicles from the Clark County right-of-ways.

Clark County Coroner's Office

- investigates deaths in traffic crashes,
- removes deceased victims at incident scene, and
- assists in leadership efforts at the TIM in order to develop policies and support regional "quick clearance" agreements.

The Clark County Office of Emergency Management and Homeland Security:

This agency has no direct operational responsibilities in incident management and clearance. However, it plays a strategic role in emergency management, focusing on policy decision making, identification of resource capabilities (ingress / egress), and managing public information as well as rumor control. It collaborates with other agencies.

Clark County Fire Department (CCFD):

- is the primary emergency response/ incident command agency for fire suppression, hazardous material spills, rescue, and extraction of trapped crash victims in Clark County;
- responds to incidents involving fire on the highway corridors located in Clark County;
- contacts Clark County Environmental/ Risk Management in cases where there is a HAZMAT spill;
- may call a contractor to clean up a HAZMAT spill on county-owned roads;
- plays a role in incident clearance once an incident scene is stabilized (CCFD either lets the civilian or the police agency on scene – either Metro or Highway Patrol – contact tow services; and
- collects incident data.

Clark County Public Works (Maintenance):

- closes and reopens roadways for use generates a report of the incident,
- maintains and repairs Clark County traffic signals and roadside equipment on County right-of-ways,
- communicates during incidents with Metropolitan Police Department (MPD) and North Las Vegas Police Department (NLVPD) using a dedicated radio channel, and
- responds to requests for assistance from NHP for CC-215 highway.

The Public Works for North Las Vegas and Henderson:

- closes and reopens roadways for use, and generates a report of the incident; and
- communicates with RTC FAST center as well as the local police department for traffic management and signal repairs, when necessary.

The Clark County Regional Flood Control District (RFCD):

- participates only in flash flood events, and
- collects data and shares with other agencies.

The City of Henderson Police Department (CHPD)

- serves as the Public Safety Answering Point (PSAP) taking 911 calls for Henderson;
- plays a role in incident management and clearance reporting incidents;
- preserves evidence, reopens roadways for use, and generates reports of the incident in the Henderson area;
- communicates with MPD and NLVPD using a dedicated radio channel; and
- utilizes CAD technology to aid communication with NLVPD.

The Freeway and Arterial System of Transportation (FAST):

- operates the RTC FAST Center and performs traffic monitoring and control by means of CCTV, detectors, Dynamic message signs (DMS), ramp meters, and Freeway Management System (FMS) software;
- has full access to most signal controllers in the Valley, and is capable of implementing special signal timing plans to assist in traffic diversion during an incident;
- communicates face-to-face with NHP during incidents;
- provides data and tools to identify incidents, traffic diversion, and assists with remote monitoring of the incident scene;
- provides diverted motorists with detour route information during incidents; and
- supports the Traffic Incident Management (TIM) Coalition by working with NDOT to support meetings.

The Regional Transportation Commission (RTC) of Southern Nevada Citizens Area Transit (CAT)

- sends out its own investigative unit when there is a transit vehicle crash;
- has contracts for vehicle removal, debris clean up, and Hazmat clean up for a crash involving a transit vehicle;
- provides drivers with amber alerts and transit watch alerts;
- produces transit bus detour routes; and
- shares incident information with law enforcement agencies as well as Office of Homeland Security, when requested.

3.2.4 Private Partners

The American Medical Response (AMR):

- receives calls from 911 or NHP to transport patients from the incident to a hospital, and
- provides pre-hospital assistance at the scene.

Towing and Recovery Operators:

- removes wrecked or disabled vehicles and debris from incident scenes, and
- work with TIM partners to adhere to the regional quick clearance agreement.

HazMat Contractors:

- clean up and dispose of toxic or hazardous materials, and
- work with the TIM partnership to adhere to the regional quick clearance agreement.

3.3 Identification of Problematic Areas in Incident Management

3.3.1 Communications

Technical Level

According to the NHP in one of the TIM meetings, better interoperability is needed in the entire region for communications. A statewide radio system would be useful as would a statewide CAD system.

Currently, there are no common communications platforms among first responder agencies. Therefore, communications must be done either through dispatch before arriving at the scene or when the units arrive at the scene.

TIM identifies the following communication methods that are being used, as stated in the *Existing Conditions* document (7):

Face-to-Face communications mainly occur at Joint Operations Centers or during task forces for on-scene coordination and planning.

Remote Voice by means of standard telephone and facsimile are the primary means of inter-agency communications. In addition, cellular phone, land mobile radio, public safety radio, and handheld state patrol radios are used. For security reasons, standard telephone communications are more widely used than radio systems.

Electronic Text communications, including alphanumeric pagers, cellular text messaging, and emails are not widely used among emergency responders in order to share incident information. However, they are often used for inter-agency communications.

Other Media and Advanced Systems include a wide range of surveillance and communication technologies that utilize video systems, roadway sensors, dynamic message signs, highway advisory radios, and the World Wide Web. The information gathered by the surveillance devices is used to detect and respond to incidents, manage traffic, and inform motorists.

Operational Level

The following are the communications platforms currently used by first responders, as listed in the *Existing Conditions* document (7):

- **OpenSky 700 Megahertz (MHz)** currently is being developed by Las Vegas Metro for communications; anticipated completion is August 2009. Once it is complete, NHP will have capabilities to operate on this system.
- **800 MHz** is used by Nevada DOT, NHP, UNLV, Nevada Power, and Capital Police (State Government offices). This system, deployed by NDOT and other state partners, is referred to as the Nevada-shared radio system. Metro's radios for the 700 Open Sky system will work with this system. The Cross Banding Repeated Project will connect the 800MHz radio systems into the 150MHz radio system so that first responders will be able to communicate by radio.
- **150 VHF channel** and 800 MHz are tied together throughout the Las Vegas region. There is a project underway to continue this effort throughout the state. There is no known completion date.
- **VHF** is used by Clark County Fire and Metro. When Metro completes their 700 MHz system, very likely they will stop using the VHF channels.

- **Southern Nevada Area Communications Council (SNACC)** has 7000 subscribers using this system. SNACC is funded by each agency and managed by committee. Users of the system include: Clark County Fire Department, City of Las Vegas, City of North Las Vegas, Las Vegas Valley Water District, Clark County Water Reclamation District, Clark County School District, City of Henderson, Paiute Indian Tribe Boulder City, the State Gaming Control Board, McCarran Airport, and North Las Vegas Fire Department. The cost is \$1800/subscription per year and \$500/radio per year.
- **Landline, phone or face-to-face, dispatch-to-dispatch** are used by NHP to communicate with most first responding agencies.

3.3.2 Lack of Live Informative Incident Data

Emergency responder agencies, such as Clark County Regional Flood Control District (RFCDD) and NHP outside the operation time of FAST, suffer from a lack of means to verify information on roadways. First response agencies are not aware of any established route diversion plan for the metropolitan area. Real-time traffic information, information regarding the best route to the scene, and predetermined detour plans at the time of an incident can tremendously improve the operations of the responding agencies. Overall, an improved communications between FAST and emergency responders is crucial. Communications with FAST at various stages of the incident management is necessary, such as detection, verification, response, on-scene management, clearance, and recovery. Refer to the Proposed Enhanced IM Communication and Data Collection System Using Smart phones in Section 6 Figure 6.3.

3.3.3 Response Time

Public Service Answering Points (PSAP)

There are four "Public Service Answering Points" (PSAP) in the region. Integration of 911 and FAST is suggested for faster incident detection as well as for information dissemination and traffic control.

Towing

A better response time towing services is needed, and more training is suggested.

HAZMAT

In incidents that involve large vehicles, there is a need for an improved HAZMAT response in order to clear commercial vehicles off the road. When a spill occurs, another obstacle is that companies do not easily approve moving HAZMAT and vehicles involved with HAZMAT incidents.

Coroner

As soon as the police verify a fatality, the coroner's office must be informed. The coroner's response time must be improved since it greatly effects the incident clearance time. An additional fund for the region is needed in order to enhance the incident investigation process. Forming a fatality team was suggested a few times.

Freeway Service Patrol (FSP)

Enhanced communications among FSP and other emergency responders are needed. Furthermore, access to FAST data and traffic control equipment is needed. FSP expressed the need for help on the scene of the incident when an injury or fatality is involved.

3.3.4 Recurring and Non-Recurring Congestion

Recurring traffic congestion on freeways has multiple sources, such as commuters and construction zones. Further complications can be introduced when primary and secondary incidents take place, causing non-recurring incidents.

3.3.5 Clearance Time

The average clearance time of incidents that involve fatality can extend to more than 6 hours. Incident clearance requires good communications and cooperation among all involved agencies. Normally, investigation is the most time consuming aspect of incident clearance.

3.3.6 Safety

On-scene safety for emergency responders is recognized to be an issue by many agencies. Truck parking for Fire and other agencies can be an issue. For instance, the Fire Department might park the truck across multiple lanes in order to provide a safer environment for responders.

3.3.7 Public Information Dissemination and Training

Public education is needed regarding the "Move It" law for minor non-injury accidents, fender benders, or incidents involving property damage only. Coordination is needed of flood and weather information that is provided to travelers. In terms of accurate traffic information, it is crucial to enhance and market the 511 system to the public, especially since Las Vegas has 45,000 visitors per day. Event management communication and coordination is also very important.

3.3.8 Performance Measures

Secondary Incidents

Nationally, secondary accidents are a challenge and make up anywhere from 15 to 20% of all accidents. Locally, the region has not set up performance measurements to track the exact number of accidents attributed to secondary traffic incidents.

3.4 Traffic Incident Management (TIM) Coalition Policies and Procedures

3.4.1 Background

Policies and procedures were revisited throughout 2009 and finalized in March 2010. Currently, policies are limited by Las Vegas TIM boundaries, as defined by the southern Nevada TIM Coalition. The purpose of the policy placement, as stated in the *Traffic Incident Management Policies for Southern Nevada* document (9) is: “Regional policies for traffic incident management (TIM) model national ‘Best Practices’ involving multi-agencies and multi-discipline response to open roads/quick clearance (QC).”

3.4.2 Policies

This section lists the policies placed by TIM Coalition Members, as stated in the *Traffic Incident Management Policies for Southern Nevada* document (9).

Regional Multi-Agency, Multi-Disciplinary Open Roads Policy

TIM Coalition members will collaborate to safely clear highway incidents within the mutually agreed upon goal of 30 minutes for non-injury accidents; 60 minutes for accidents involving injuries; and 90 minutes for fatality crash scenes, spill/contaminants, and “big rig” overturns. Other Quick Clearance (QC) policies will be initiated to support this policy. The TIM Open Roads Partnership Agreement shall be the guiding document for defining quick clearance regional traffic incident management policies.

Performance Measurement Goals Policy

First Responder agencies in the TIM Coalition boundaries will work with the TIM leadership to identify ways to measure both response times for each agency and also roadway clearance times for each incident. A regional report reflecting regional open roads performance (open, partially open or closed) toward the TIM Open Roads Partnership Agreement goals will be developed from information provided primarily from the NHP CAD as well as other data gathered from TIM Coalition members. The Agreement outlines roadway clearance goals of 30 minutes for non-injury accidents, 60 minutes for multiple car and/or injury accidents, and 90 minutes for multiple injury and/or fatality traffic incidents.

Incident Response Vehicle (IRV) Policy

Traffic incidents involving multiple vehicles, fatalities, “big rig” overturn, or contaminant/spills, shall have an incident response vehicle (IRV) dispatched to manage traffic; the IRV will also assist Incident Command at the scene with quick and decisive clearing of the highway. Further, through NDOT, the TIM Coalition will insure that IRV drivers are fully trained with the most recent information available on traffic management and contaminant/spill response.

TIM Lighting Policy Agreement

Public Safety and other Traffic Incident responders will examine their policies and actual practices for the use of emergency vehicle lighting; from this evaluation, they will set a goal to reduce the number of emergency lights at secured incident scenes. Forward lighting should be limited to travel to or from a major incident, and special consideration should be given to extinguishing all forward-facing flashing or wig-wag emergency lights, especially on divided highways. Once adequate traffic control has been established and orange cones have been placed to assure a lane of safety, amber lights are recommended for use by all TIM responder agencies at the scene of an incident, that is, fire, law enforcement, NDOT, towing, etc. It is understood that this policy could take several years for such vehicles as fire engines and other expensive first responder vehicles can be replaced with newer vehicles having amber lighting options available.

Apparatus Placement and Scene Protection Policy

For the safety of first responders serving a scene, whenever possible, lane blocking should be limited to initiating one additional lane of barrier protection. Apparatus placement at the scene of a traffic incident should be in compliance with agreed-to TIM Emergency Responder Parking Order and Cone Placement; this apparatus should be parked off the road whenever possible unless being used to create the lane of safety. Graphic placement cards for Emergency Responder Parking Order and Cone Placement should be placed in each EM vehicle for quick reference.

Multi-Disciplinary NIMS and TIM Planning/Training Policy

All first responder agencies located in the TIM boundaries shall promote cooperation, coordination, communication, and consensus building in order to support the regional Open Road Partnership Agreement dated October 28, 2008. The TIM Coalition will work together toward assuring that all TIM responders receive multi-disciplinary National Incident Management Systems (NIMS) and TIM training. TIM members will develop a regional approach to TIM planning, training, and policies for the Las Vegas region.

TIM Fatality Investigation Policy

In the event of a fatality or major traffic incident, whenever possible, the investigative technology used should include Photogrammetry in order to allow 3D reconstruction of the incident away from the incident scene, ensuring a safe environment for the first responder. Also, this allows for quicker clearance of roadways and decreases the likelihood of secondary incidents, thereby offering greater safety to both emergency responders as well as the traveling public.

Removal of Decedents from Fatality TIM Scene

NHP will notify the County Coroner within 15 minutes of identifying that there has been a traffic incident with a fatality. It shall then be the policy of the Clark County Office of the Coroner/Medical Examiner (CCOCME) to appropriately investigate and remove victims of fatality accidents from the Traffic Incident Management (TIM) corridor in the most expeditious manner possible. The CCOCME may choose to allow another first responder authority to remove the victim from the place where the body has landed or allow the body to be removed with the "jaws of life" before investigation has been completed, as long as digital photographs have been taken for later investigations.

First Responder Communications for In Route and On-Scene

Traffic incident responders will work together through the TIM Coalition to develop and implement standardized multi-agency, multi-disciplinary communications practices and procedures for traffic incidents among ALL first responders. This is including, but not limited to, face-to-face communications in the regional traffic management center (NHP-FAST Center); remote voice radios, whenever available; electronic text; use of CCTV cameras; and any other means available in order to insure prompt, seamless response to traffic incidents.

Effective Use of TIM Technology and Responder Availability

The FAST TMC provides CCTV camera surveillance and the availability of Dynamic Message Signs (DMS) for transportation and emergency management personnel 24/7. It is the regional policy of the TIM Coalition that all appropriate first responder agencies (Las Vegas Metropolitan Police Department, Clark County Fire Department, etc.) may have access to CCTV cameras for verification of traffic incident severity as well as to commit assets to respond. In order to manage traffic 24/7, emergency dispatch for NHP will continue to have access to cameras and DMS for monitoring and working with FAST TMC. A regional goal is targeted for 2010 to provide operators who will input real time travel and accident clearance data into the statewide 511 system. NDOT maintenance will have dispatching capabilities 24/7 from the FAST center operations floor. Also, for major incidents - defined as multi-vehicle, fatality, big rig truck or Contaminant/spill incidents - RTC FAST will manage arterial traffic in order to divert freeway traffic.

Wrecker Operator and Truck Requirement Policy

Towing operators will have operator training and TIM-approved driver certification for towing all classes of vehicles. NHP will keep a list of approved

towing companies. NHP dispatch will notify the towing company of vehicle class they will be towing, according to the TRAA Vehicle Identification Guide. Towing companies will respond within 30 minutes of notification to appear at the scene. A company with 2 missed calls in one month will be considered for a 30-day suspension. Tow companies are required to clear all travel lanes within 60 minutes once they have been given the "go ahead" by the Incident Command officer on scene.

Spills/Contaminates Removal Policy

NDOT shall provide for State of Nevada highways, and Clark County will provide for Clark County highways, services for the primary purpose of clearing spills/contaminates, and overturned big rigs from the mainline thoroughfares as quickly as possible, thus allowing unimpeded and continued traffic flow. Specific procedures for use of this contracted service shall be defined in guidelines separate from this policy.

Unified Command System for Traffic Incident Management

Police is the primary emergency response incident command agency for traffic incidents on the highway. The fire department is the primary emergency response incident command agency for fire suppression, hazardous materials spills, rescue and extrication of trapped crash victims. In the event of a fatality, overturned "big rig," contaminant/spill, or other major traffic incident that will take 60 minutes or longer to clear, the Unified Command System (reference graphic below) will be used for the TIM region, stressing a partnership. The first responder to arrive on the scene will be responsible for forming a unified command structure upon arrival of other first responders. Input is encouraged from all agencies represented at the scene to develop a well-coordinated management strategy for clearing the scene as safely and efficiently as possible. Responsibility for specific actions discussed and decisions made shall follow best practices, as defined by TIM policies agreed to by the TIM Coalition.

Multi-Agency, Multi-Disciplinary TIM Plans for Construction

In order to engage the TIM members responsible for maintenance, enforcement, and operations of the corridor being considered for construction, highway construction projects required to prepare a TIM Plan under Manual on Uniform Traffic Control Devices (MUTCD) guidelines will be presented by the sponsoring agency representative, preferably the Project Manager, during the design phase of the project.

TIM after Action Incident Review Debriefing Policy

Any incident taking longer than 90 minutes to clear from the roadways will trigger a debriefing of that traffic incident at the next regularly scheduled TIM Coalition meeting. The purpose of the debriefing is to determine what, if anything, could have been done differently to achieve the 90-minute regional clearance goals. The After Incident Review Procedures will be adhered to for scheduling and conducting the debriefing. All agencies who participated in the original traffic incident will participate in this valuable process.

3.5 A Joint Operations Policy Statement Agreement (JOPS)

This policy agreement is developed by several emergency responder agencies in cooperation with Delcan and Iteris. The agreement was signed on November 18, 2010 between the Nevada Department of Public Safety, Nevada Highway Patrol, and the Nevada Department of Transportation.

3.5.1 Policies in the Agreement

The following are the policies listed in the "Joint Operations Policy Statement (JOPS)" document (8).

3.5.2 Data Sharing

Nevada department of Transportation (NDOT) and Department of Public Safety (DPS) intend to share information needed to facilitate joint operations of state highways. Available data will be shared between agencies at the same cost as if the data were being shared between programs within the agency. Cost recovery data will be shared at the same rate. When needed, a Memorandum of Understanding will be signed to document the sharing of information.

3.5.3 Coordinated Communications

Coordinated Public Information:

It is the policy of DPS- Nevada Highway Patrol (NHP) and NDOT to coordinate public information messages and outreach on issues, when possible, that affect both agencies and/or their customers. Sample issues include: highway incidents, weather related (i.e., wind, winter driving, etc.), work zone safety, and/or new policy initiatives for communications. Each agency will coordinate with the other on any messaging which impacts both agencies prior to releasing the information.

Traveler Information and Media Releases:

It is the policy of NDOT/DPS to communicate timely and accurate travel conditions to the public, including restrictions and information on incidents that allow the public to make informed decisions about their travel route and safety. To accomplish this, it is the policy of NDOT and DPS to provide information to traffic management centers (i.e., Northern Nevada Regional Traffic Operations Center, FAST and Elko Traffic Ops Center) to update the Dynamic Message Signs (DMS), the internet, 511, the media, and Highway Advisory Radio (HAR) where applicable. The goal is to provide relative real time information to travelers and update information within 15 minutes of a condition change.

3.5.4 Traffic Incident Management - Safe Clearance

Open Roads Policy:

Open Roads is a term used to reflect a commitment on behalf of the state of Nevada Department of Public Safety and Department of Transportation to open the Nevada roadways following a traffic incident in an urgent manor for the safety of ALL responders at incident scenes and for motorists traveling in Nevada. It is a mutual goal of the DPS and NDOT to collaborate to safely clear highway incidents within the mutually agreed upon goal of 30 minutes for non-injury accidents, 60 minutes for injury accidents and 90 minutes for fatality crash scenes, spill/contaminants or load recovery and large vehicle overturns in the Las Vegas region in accordance to the TIM Open Roads Partnership Agreement. In Elko and Reno regions the DPS/NDOT goal is to develop TIM Coalitions and work together to safely clear highway incidents within 90 minutes. This policy goal means that DPS and NDOT will work cooperatively and effectively with all first responders to efficiently manage resources responding to, mitigating, investigating, and clearing highway lanes in order to minimize traffic disruption.

Freeway Service Patrol (FSP) Program:

NDOT will provide “roving” freeway service patrols (FSP) to proactively prevent accidents and capacity-reducing incidents by assisting broken-down motorists on congested freeways and highways. During the highest congestion times and during traffic incidents, these FSPs may be radioed directly by DPS Dispatch to request assistance. Radios are provided to FSPs for direct contact with DPS by NDOT. FSP has qualified staff with medical and mechanic skilled training. NDOT will endeavor to increase hours of FSP to extend services from 7:00 p.m. to midnight on agreed upon corridors.

Incident Response Vehicles (IRVs):

NDOT is implementing a pilot program within the next 12 months from the date of this JOPS Agreement to add at least two Incident Response Vehicles (IRVs) to the Las Vegas region. This pilot program includes the 1) ability to provide traffic control for safe incident zones, 2) use mobile DMS, 3) quick clearance and, 4) traffic condition information to the TMC as well as periodic updates to traveler information. Expansion to statewide is expected shortly after the pilot program is completed. NDOT and DPS will reevaluate the pilot program and possibly rollout IRVs in Northern Nevada.

Dispatch for Quick Clearance:

It is the policy of NDOT and DPS to provide timely and accurate communications during incidents among dispatchers and to have a Quick Clearance goal of 90 Minutes. DPS and NDOT will work together to define specific guidelines for a Instant Tow Program in the Las Vegas TIM Coalition area. DPS Dispatch will call for a towing company to provide Instant Towing immediately after dispatching responders to a 911 call. NDOT maintenance will endeavor to have dispatching capabilities from the Traffic Management Center floor of FAST and of the days a week, planned Northern Nevada Regional Operations Center (NNROC). FAST will manage arterial traffic 24 hours a day to divert freeway traffic for major incidents (defined as multi-vehicle, fatality, and “big rig” truck or contaminant/spill incidents).

Major Incident Towing:

It is the policy of the Department of Public Safety (DPS) to maintain and use a rotating list of towing companies for the dispatchers. DPS will maintain a contract with tow operators, and DPS Dispatch will contact towing companies based on their rotation and in accordance with the Nevada Highway Patrol Tow Car Manual. Towing operators are required to have Tow Operator training. NHP Dispatch will notify the towing company of the class of vehicle they will be towing, according to the Towing and Recovery Association of America (TRAA) Vehicle Identification Guide.

Using Technology to Expedite Investigations:

Every effort will be made, in a coordinated fashion, to achieve all responders’ objectives at incident scenes and to have roadways open and operating in 90 minutes or less. NDOT and DPS will aggressively pursue, within financial constraints, any technology that reduces the scene investigation time, including but not limited to Photogrammetry.

Hazardous Materials, Other Spills and Load Recovery Policy:

NDOT and DPS will coordinate quick clear efforts for Hazardous Material Contaminant / Spills. NDOT will provide environmental contracting services on State right-of-ways for the primary purpose of clearing spills/contaminants and overturned “big rigs” from the mainline thoroughfares within the targeted timeframe goal of 90 minutes. Load recovery will continue to be the responsibility of the owner of the load.

Unified Command Policy:

DPS and NDOT agree to use the Unified Command Policy approved by the TIM Coalition and advocated by the National Incident Command Management System (NIMS) for all highway incidents and disaster management activities that are appropriate for example, incidents that will require more than 60 minutes to clear from the roadway. Both DPS and NDOT agree to be NIMS compliant in accordance with ongoing federal requirements, and maintain relationships with local and applicable jurisdictions.

Performance Measures:

DPS and NDOT will work together to identify ways to measure 1) response times to incidents for each agency, 2) roadway clearance times for each incident, and 3) secondary crashes. A regional report reflecting these three measurement goals will be developed from information provided primarily from the DPS RMS/CAD and NDOT Traffic Management/Traffic Operations Centers; this will commence when new DPS CAD (RMS) is implemented. In As the JOPS Implementation Plan is being developed, regularly scheduled intervals will be defined. The intended goal will include relative real time performance measures with automated features on the internet.

3.5.5 Enforcement and Traffic Control

Traffic Incident Management Plans for Construction:

Major highway construction projects are required to have a plan for managing traffic incidents under NDOT’s Work Zone Implementation Plan as well as the Manual on Uniform Traffic Control Devices as per MUTCD Guidelines and State of Nevada Guidelines . In order to engage DPS and NDOT departments responsible for enforcement and operations of the corridor being considered for construction, it is the policy of NDOT and DPS to have contractors present construction incident management plans for major projects to the Traffic Incident Management Coalition / DPS / First Responders by the sponsoring agency representative (NDOT or contractor Project Manager) during the design phase of the project.

Traffic Incident Management Plans for Planned Special Events:

Periodically, events are held on state highways and interstate freeways such as dignitary protection services, NASCAR races, marathons, and New Year's Eve Events. It is the policy of DPS and NDOT to work together so that safety and security concerns are addressed and traffic/crowd control strategies are coordinated and developed for each event. This is to include permitted events and events not requiring a permit like funeral processions, and motorcades.

Work Zone Safety:

Each day, highway workers and enforcement officers undertake their jobs alongside of traffic in locations that routinely have significantly elevated risks on the State's transportation infrastructure. Their safety and the safety of the traveling public is a top priority of NDOT and DPS. It is the combined policy of DPS/NDOT to achieve the highest level of safety in work zones through NDOT developing effective work zone strategies to ensure safety and DPS enforcing existing and new regulations in work zones. NDOT and DPS will work together to maintain or improve work zone safety in those areas that will benefit from combined expertise and resources.

Emergency Operations, Significant Events, and Heavy Tourist Traffic:

DPS and NDOT acknowledge that appropriate maintenance operations, communications, signage and enforcement are key elements to providing safe motorist travel during events. Each agency will respond to requests for service by the other with a joint commitment to enhancing motorist safety and mobility.

3.5.6 Shared Facilities and Transportation Security

Shared Facilities:

NDOT and DPS are committed to working together and sharing facilities whenever feasible in order to improve communication, improve working relationships and reduce costs. If necessary, NDOT and DPS will sign a separate agreement that identifies specific arrangements for space, funding and security for shared facilities.

Highway System Security:

NDOT and DPS are committed to highway system security and agency preparedness. NDOT and DPS will be mutually responsible for transportation system security. DPS will serve as a liaison to NDOT where necessary to ensure pertinent information or intelligence assuring potential or credible threats to Nevada's Highway System is communicated promptly and accurately.

Safety Rest Areas:

NDOT and DPS will work together to ensure that operations and security of the Safety Rest Areas and Weigh Stations are conducted to maximize the public health and, safety.

3.5.7 Wireless Communications

The DPS and NDOT agree to support a shared vision to create a coordinated and integrated wireless transportation communications for the safe, effective and efficient protection of the traveling public.

3.6 TIM Self Assessment

The TIM program has scored 71% in its 2010 self assessment, which was conducted by giving out a questionnaire designed to extract input from TIM members based on a number of strategic, tactical, and support criteria.

3.6.1 TIM Self Assessment Scoring Scheme

Listed below are the scoring schemes for TIM's self assessment:

L (LOW)

Little to no activity in this area. No discussions or some informal discussions with no or minimal action taken.

M (MEDIUM)

There is some or good level of activity in this area. Procedures have been put into practice with some multi-agency agreement and cooperation, with fair to good results.

H (HIGH)

Activity in this area is outstanding. Efforts in this area are well coordinated, with a high level of cooperation among agencies.

3.6.2 Supplemental Score

Listed below are the supplemental scoring criteria:

L (LOW)

- **N = No Activity-** No activity or discussion of this issue
- **S = Some Activity-** The issue has been acknowledged and there has been some activity by a single agency.

M(MEDIUM)

- **F = Fair Level of Activity-** Some good processes exist, but they may not be well integrated or coordinated.
- **G = Good Level of Activity-** Efforts in this area are strong and results are promising, although there is still room for improvement.

3.6.3 TIM SA Questions

TIM self assessment questions spanned three categories strategic, tactical, and support. Each category encompasses several assessment schemes as listed below:

Strategic

1. Formal TIM Programs
2. Multi-Agency TIM Teams
3. Performance Measurement

Tactical

1. Policies and Procedures for Incident Response and Clearance
2. Responder and Motorist Safety

Support

1. Data Collection/Integration/Sharing
2. Traveler Information

3.6.4 TIM SA Questionnaire and Scoring

The following are the questions that were provided in the TIM self assessment questionnaire:

Supplemental Questions

1. Is there a process in place that allows for training of responders and supervisors on the content of the MOUs? Yes / No; If yes, describe:
2. How often is the document updated?
3. How frequently are meetings held?
4. Please indicate which types of Other Training: Basic Multi-agency TIM / Traffic Control / Work Zone Safety / Safe Parking
5. Is there a define incident level or threshold at which mandatory multi-agency post-incident reviews are conducted? Yes / No; If yes, what is that level? How many post-incident reviews were held in the last 12 months?
6. Is data being collected on any other measures (i.e. DOT response time)? Yes / No; If yes, describe:
7. If there is a safety service patrol, please provide details on level of service including lane miles covered, hours of operation, services provided, availability of staff 24/7 for immediate response.

Strategic

The Strategic section of the assessment contributed 30% of the overall score. TIM has scored 21%/30%.

Formal Traffic Incident Management Programs

The survey questions are listed below. The survey responses are listed immediately after every question in italic.

1. Is the TIM program supported by multi-agency agreements/memoranda of understanding detailing coordinated objectives, roles and responsibilities and safe, quick clearance goals?
2. **Rating: H- The TIM Coalition meets semi monthly, and has an agreement in place signed by all local stakeholders. There are approved quality control policies and procedures are in development.**
3. Is there a process in place to ensure the continuity of these agreements/memoranda of understanding through integrated planning and budgeting across and among participating agencies?
4. **Rating: G - A strategic action plan for TIM projects is reviewed by the TSC but not budgeted across agencies.**

Multi-Agency TIM Teams

Does the TIM program:

1. Have a formalized TIM multi-agency team or task force which meets regularly to discuss and plan for TIM activities?
2. *Rating: H, TIM Coalition meets bimonthly.*
3. Conduct training: NIMS?, Training of program managers from primary agencies on the NTIMC National Unified Goal?, other?
4. *Rating: H, H, G, training held annually, training held annually, Quick Clearance training occurs annually. TIM also sponsored Photogram training for law. Need HazMat, IRV, Traffic Control, Work Zone & other training for TIM, etc.*
5. Conduct post-incident debriefings?
6. *Rating: H, Incidents are recorded by the FAST TMC and they are used for training and debriefing at TIM meetings. The local threshold for review is anything longer than 90 minutes in the agreement. There has been at least 15 post incident reviews because there are 2-3 at each TIM mtg.*
7. Conduct planning for special events: Construction and maintenance?, Sporting events/ concerts/ conventions/ etc?, Weather-related events?, Catastrophic events?
8. *Rating: H, H, H, TIM Coalition members help form construction TIM plans. Las Vegas meetings for their major New Years Eve event. No action is really needed here in Las Vegas. This is not under the TIM Coalition but it is done.*

TIM Performance Measures

1. Have multi-agency agreement on the two performance measures being tracked: Roadway Clearance Time?, Incident Clearance Time?
2. *Rating: F, F, Actions are still being finalized. Lots of discussions, some info collected and we have defined what we want to collect but are still trying to identify how to collect the information consistently.*
3. Has the TIM program established methods to collect and analyze the data necessary to measure performance in reduced roadway clearance time and reduced incident clearance time?
4. *2. Rating: S, No formal methods to analyze the data has been defined, still in process. Very close to making some decisions. Working with UNLV and their students.*
5. Have targets (i.e. time goals) for performance of the two measures?
6. *Rating: H, The region has defined target goals of 30, 60 and 90 minute clearance times. We have not measured it but are confident that the region has made huge strides toward the goals.*
7. Routinely review whether progress is made in achieving the targets?
8. *Rating: S, Still defining methods of reviewing progress on achieving targets. We can visually see a change but can't show it.*

9. Track performance in reducing secondary incidents?
10. *Rating: S, We are working with UNLV in identifying and reducing secondary incidents have awareness.*

Tactical

The Tactical section of the assessment contributed 40% of the overall score. TIM has scored 30.8%/40%.

Policies and Procedures for Incident Response and Clearance

Does the TIM program:

1. Have “authority removal” laws allowing pre-designated responders to remove disabled or wrecked vehicles and spilled cargo?
2. *Rating: H, The law needs to be modified - it gives 24 hours before removal - too long.*
3. Have “driver removal” laws which require drivers involved in minor crashes (not involving injuries) to move vehicles out of the travel lanes?
4. *Rating: H, Does have the law but public is not aware of it. The law needs to be modified to remove the requirement for returning to the scene and waiting for officer.*
5. Use a safety service patrol?
6. *Rating: G, FSP covers EMT services, minor mechanical, gas, flat tire, etc. They also assist NHP when requested. They are roving and cover 86 centerline miles, M-F from 6 am- 7 pm. 10-6 on Sat/Sun. They are not equipped for Incident Response Vehicle and do not have signs for rerouting traffic.*
7. Utilize the Incident Command System?
8. *Rating: H, Need more regional training in unified ICS for transportation folks. Emergency first responders use ICS but according to a recent review by homeland security regionally, it is weak.*
9. Have response equipment pre-staged for timely response?
10. *Rating: S, No staging has occurred but discussions are underway in the TIM regarding possible pre-staged response.*
11. Identify and type resources so that a list of towing, recovery and hazardous materials response operators (including operator capabilities and special equipment) is available for incident response and clearance?
12. *6. Rating: H, There is a list that is used by NHP based on skills. This is an area that has excelled with TIM involvement. NDOT has issued an environmental contract for spill cleanup and Clark County has one for their right of way. Future effort will include modified policies for vehicle removal and more training in multi-agency HazMat & spill response.*

13. Is that list organized so that resources are identified and deployed based on incident type and severity?
14. *Rating: H, The list of towing companies are kept by NHP. Environmental Spills are cleaned through contracts with either Clark County or NDOT.*
15. Have specific policies and procedures for hazmat and fatal accident response that also address maintaining traffic flow around the incident? for hazmat response?, for fatal accident response?
16. *Rating: G, Written - still being worked out for procedures.*

Responder and Motorist Safety Does the TIM program:

1. have “move over” laws which require drivers to slow down and if possible move over to the adjacent lane when approaching workers or responders and equipment in the roadway?
2. *Rating: G, Yes NRS 484B.607 but the law needs to be modified.*
3. train all transportation responders in traffic control following MUTCD guidelines?
4. *Rating: F, Trained in Quick Clearance. Still working on Traffic Control Training and MUTCD guidelines.*
5. utilize transportation resources to conduct traffic control procedures for various levels of incidents in compliance with the MUTCD?
6. *Rating: G, The level of response has been defined at 30, 60 and 90 minute clearance to go with various incident levels of fender benders to fatalities. Procedures still being worked out.*
7. utilize traffic control procedures for the end of the incident traffic queue?
8. *Rating: S, The end of the traffic queue is just now under discussions. Focus has been on the initial incident.*
9. have mutually understood equipment staging and emergency lighting procedures on-site to maximize traffic flow past an incident while providing responder safety?
10. *Rating: H, Policies have been approved for emergency lighting and vehicle parking on the scene to maximize traffic flow past an incident to provide responder safety.*

Support

The Support section of the assessment contributed 30% of the overall score. TIM has scored 19%/30%.

Data Collection/ Integration/ Sharing

1. Does the TIM program use a Traffic Management Center/Traffic Operations Center to coordinate incident detection, notification and response?
2. *Rating: G, Not sure how much notification and response are coordinated by the TMC.*
3. Is public safety co-located with transportation in the TMC/TOC?
4. *Rating: H, Yes - NHP HQ is with FAST TMC.*
5. Has the TIM program achieved TMC-CAD integration so that incident data and video information is transferred between agencies and applications?
6. *Rating: S, Data is not automated between the CAD and the TMC.*
7. Does the TIM program have specific policies and procedures for traffic management during incident response (i.e. signal timing changes, opening/closing of HOV lanes/ramp metering)?
8. *Rating: S, The TIM has specific policies and procedures for first responders but not for signal timing changes, etc, maybe for the future.*
9. Does the TIM program provide for interoperable, interagency communications on-site between incident responders?
10. *Rating: F, Not sure that the FAST TMC sees this as their responsibility.*

Traveler Information

Does the TIM program:

1. Have a real-time motorist information system providing incident-specific information? Traveler information delivered via 511?, Traveler information delivered via website?, Traveler information delivered through traffic media access to TMC/TOC data/information?
2. *Rating: S, H, H, Formal discussions but 511 real time info is not available in Las Vegas. Traveler info is available through RTC-FAST. Thru FAST there is some traveler info. There is incident info through the TIM website from NHP and construction info from NDOT. Yes through RTC website.*
3. Are motorists provided with travel time estimates for route segments?
4. *Rating: H, Through FAST on DMS signs.*

Chapter 4

Meetings with Emergency Responders

Throughout the project duration, multiple meetings were conducted with several agencies in order to qualitatively understand the incident management process from various points of view. Table 4.1 is a list of the meetings that were attended.

Table 4.1: External and internal project meetings

Agency	Personnel	Description	Date- Time
FAST	Brian Hoeft and Gang Xie	FAST Data (Travel Time, Flow Detector, Travel Runs, etc.)	Regular Weekly Meetings
Fire	Richard Brenner	HAZMAT Coordinator	08/11/10 10:00 am
LVMPD	Oscar Chavez	First Responders	03/19/09 10:30-11:30 a.m.
	Beverly Chavez	Metro dispatch Center	04/15/09 9:00 a.m
NHP	Georgene Tuner	NHP Dispatch Center	05/11/09 6:30 -8:30 p.m.
TRC	Pushkin Kachroo and Neveen Shlayan	Project Updates	Regular Weekly Meetings

4.1 The Freeway and Arterial System of Transportation (FAST) Meetings Summary

FAST is one of the first integrated Intelligent Transportation System (ITS) organizations in the country. It is a department of the Regional Transportation Commission (RTC) of Southern Nevada. FAST uses all available means and resources to perform traffic monitoring and control through infrastructure as well as data. **Traffic control** is accomplished through the use of traffic signals, ramp meters, dynamic message signs, and lane control signals. **Traffic monitoring** and detection of traffic conditions are required for proper traffic control. This is achieved through the use of video image detection and inductive loop detection. Visual verification of conditions is done through closed circuit television (CCTV) cameras. The map in Figure 4.1 (posted on FAST website ([1](#))) shows the current ITS coverage.



Figure 4.1: FAST Intelligent Transportation System (ITS) Coverage. Green= Existing ITS, Yellow= under construction ITS, and Red= under planning ITS.

4.1.1 FAST Resources

Traffic Monitoring:

- **Live Traffic Cameras:** FAST has approximately 56 CCTV cameras distributed along the Interstate 15 stretch, US 95, and CC 215 providing live video feed that is used only for traffic monitoring.
- **Freeway Flow Detectors :** FAST flow detectors are a combination of loop detectors and radar. They are, approximately, half a mile spaced out throughout the major freeways: Interstate 15 (I15), US 95, and CC 215. The polling period for the flow detectors is one minute. However, sensed data is aggregated and reported over a period of fifteen minutes. The data in its raw form provides volume and speed information for every lane. Volume can also be segregated by six vehicle classifications.
- **JAMAR:** FAST uses a JAMAR system in order to collect data on arterial roads defined as **travel runs**. Travel runs are conducted sporadically or whenever needed to test the performance of certain traffic lights.

Traffic Control:

- **Dynamic Message Signs (DMS):** DMS are used to provide advisory information to drivers about incidents, events, construction and maintenance activities, road closures that affect the freeways, and freeway travel times to certain locations. DMS will display pre-set messages stored in the system as well as specific messages based on current conditions.

- **Ramp Meters:** FAST has about 45 ramp meters along the I15. The ramp meters are traffic signals with only red and green lights that control cars merging onto the freeway and they are consistently monitored by FAST to ensure that they do not create congestion on surface streets.
- **Traffic Lights:** FAST controls most of the traffic lights in the Las Vegas area. This spans placing timing plans, intersections coordination, timing plans adjustments and coordination with events such as construction and detours to accommodate unexpected additional volumes that are forced into certain routes.

4.1.2 FAST Involvement in Incident Management

FAST uses all its resources in order to maintain smooth operation of traffic. What makes FAST even more successful in accomplishing its goals is the cooperation with the Nevada Highway Patrol (NHP). FAST and NHP work together in order to handle the different stages of the incident management. FAST and NHP share the same venue. FAST crew operates the live video cameras where NHP has direct access to them during the operation hours of FAST. When FAST depicts an incident within the range of their observability, they immediately inform NHP and zoom the video camera to obtain a clearer view of the incident. This way NHP can determine the severity of the incident in a timely manner. Also, NHP will be able to make better decisions regarding dispatching units and contacting other needed agencies. This increases efficiency in operations and resource allocation. Simultaneously, FAST can easily determine the level of congestion using the available live video as well as traffic flow data; based on which, FAST will post appropriate advisory messages on their DMSs warning drivers of the location of the incident. FAST also offers a text messaging and emailing service where they inform subscribers of the location of the incident. Furthermore, based on the severity of the event, FAST can change the rate at which traffic is flowing into the freeway by using the ramp meters.

4.2 Fire Department Meetings Summary

4.2.1 Fire Department General

How does Fire Respond?

The Fire Department consists of professionally trained and specialized crews that are needed in many incidental cases. When the emergency number (911) is dialed, the call takers at the Public Safety Answering Point (PSAP) or LVMPD receive the call first and ask the caller to choose between Fire, Medical, or Police. The Fire Department responds to both Fire and Medical. If the caller chooses either one, the call is transferred directly to the fire dispatch center. Thereafter, a unit is sent to the scene. Figure 4.2 shows the process of fire response described by the Fire Department (6).

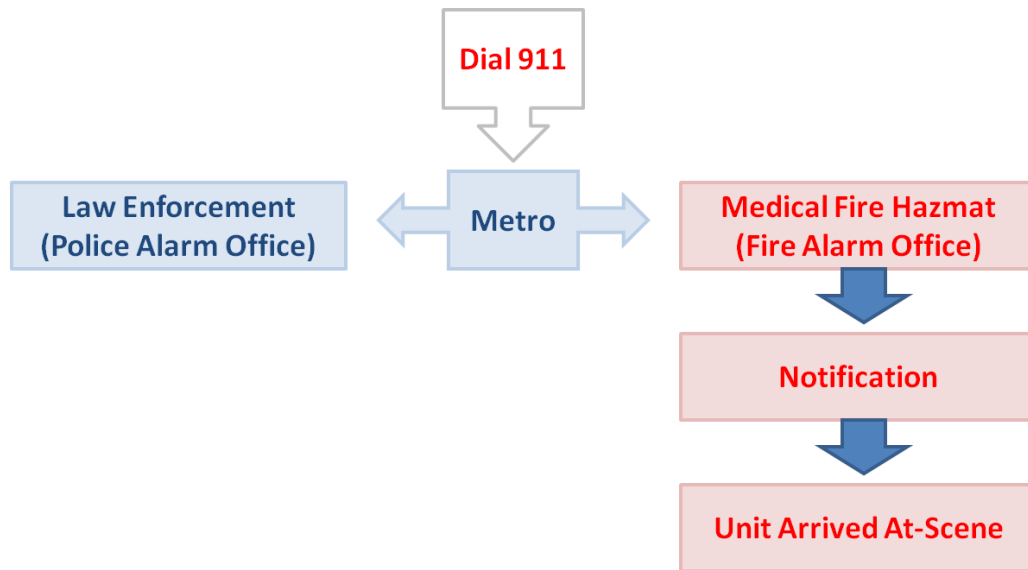


Figure 4.2: Fire response process described by the Fire Department (6)

Fire Services

- Urban fire services
- Rural fire services
- Aircraft rescue fire fighting
- Emergency medical services
- Hazardous materials response team
- Urban search and rescue team
- Technical rescue
- Disaster and Emergency Preparedness
- Public Education
- Fire Prevention

Types of Responses

- Medical
- Fire
- Technical Rescue
- Suspicious Device
- HAZMAT
- Stand
- Stand-By

Clark County Fire Resources

- Total of 42 Fire Stations
 - 29 Paid Stations
 - 13 Volunteer Stations
- Total of 122 front-line units
 - 34 Rescues: Paramedic/ Rescue is a dual response system that consists of a two person crew paramedic and EMT I. Medical emergencies is the primary responsibility.
 - 40 Engines: the primary responsibility is fire suppression. This system consists of a four person crew captain/ engineer, and two firefighters.
 - 6 Trucks: the primary responsibility is fire suppression. This system consists of a four person crew captain/ engineer, and two firefighters. In addition, specialized duties such as utilities, ventilation, life searches, salvage, and overhaul are in the span of the trucks' responsibilities.
 - 42 Other including: CBRNE Incident Response Vehicles, Rehab Unit, Air Units, Command Unit, MCI Unit, Water Tender, HAZMAT, etc.

Fire Computer Aided Dispatch (CAD) System

The Fire Department CAD system automatically assigns the proper level of Hazmat incident based on the answers to the protocol questions. There are three levels of HAZMAT:

- HAZMAT Level I, IF, and IP
- HAZMAT Level II
- HAZMAT Level III

It is important for the dispatcher to determine the level of the incident in order to dispatch the appropriate unit to the scene which will have the proper equipment to handle the given situation. Dispatching the wrong equipment results in more delay thereof, more congestion.

4.3 Las Vegas Metropolitan Police Department (LVMPD) Meetings Summary

4.3.1 LVMPD Traffic Division

LVMPD traffic division becomes involved in the incident management process when a traffic accident occurs. LVMPD receives 90% of the 911 calls for all incidents (including burglary, fire, crime, etc).

There are three possible sources where LVMPD can obtain information about a certain incident:

1. Direct call to dispatch (911 (emergency) calls)
2. Incident observed by the officer. In this case, the officer contacts the dispatch center with his radio and gives all the details about the incident (car no., location, no. of vehicles stopped, lanes blocked)
3. Direct call to the officer

All 911 calls from the Las Vegas metropolitan area are received at the LVMPD dispatch center. Nonemergency calls or 311 calls are received directly by the police department. Based on the various variables of the incident, such as location, condition, and call maker request, the dispatcher will pass the information to the proper agencies, such as Fire, Emergency Medical Services (EMS), NHP, and/ or Henderson.

LVMPD has a Computer Aided Dispatch (CAD) center that is used by call takers and dispatchers. Generally, other emergency responder agencies have their own CAD system. The different CAD systems that are used by the various agencies do not necessarily communicate with each other. In fact, they are completely independent. If the dispatcher believes that both emergency (Fire or EMS) and PD needs to attend a certain incident, then LVMPD informs both Fire and EMS. Fire has a completely different dispatch system. Dispatch center contacts all other agencies depending on the jurisdictional area where the incident occurs.

LVMPD may handle various 911 emergency calls differently upon receipt:

- If it is a traffic incident, Metro will pass the information to the traffic bureau if it falls within the Las Vegas city and the unincorporated Clark County area.
- If the LVMPD dispatcher decides that both emergency (fire or EMS) and PD need to be present, then the dispatcher will contact the Fire Dispatch which will inform both fire and EMS.
- If a criminal activity is reported, the dispatcher will inform Metro police department.
- If the call does not fall in specified jurisdiction of LVMPD, then it will be forwarded to the proper dispatch center (e.g., NHP, Henderson, and North Las Vegas).
- If Metro receives a 911 call and if the caller is not responding properly, based on the sounds they hear (screaming and shouting) the dispatch center assumes worst and informs EMS, Fire and Police. Metro can locate the telephone number and address only if the call is received from 911 not by any other means (e.g. 311 or local phone). Once the LVMPD dispatch informs various agencies, there are no further communications among them.

Response Category Profile (RCP) identifies the number and type of officers need to be present at a certain incident scene. Although all the officers are trained for most general cases, only a few are trained for special cases. Those of which must have the Crisis Intervention Trained (CIT) certification. 75% of the time, the dispatcher is able to make the decision of whether a CIT help is needed or not. However, if the dispatcher does not have enough information to determine the necessity for a CIT officer, the dispatcher will send an officer to the scene to collect more information about the incident.

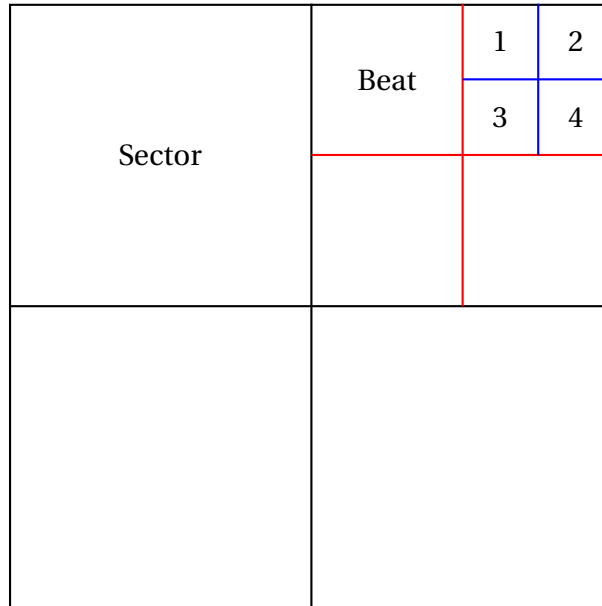


Figure 4.3: LVMPD jurisdictional boundary definitions

LVMPD is a “proactive” agency and is tied to its geographical area. In other words, LVMPD dispatchers send their units based on their jurisdictional boundaries since they are bound by geographical areas. If an incident occurs at the borders of two jurisdictions, then both corresponding agencies will simultaneously assist to clear the incident. On the other hand, the Fire Department is defined as a “responsive” agency. The Fire Department sends their units based on their relative location; the unit that is closest to the scene is the one that responds. Only in some serious exceptions, LVMPD may leave their geographical area to attend cases in other geographical areas (e.g., a police officer being attacked). LVMPD does not use GPS to track their officers’ locations, whereas the Fire and EMS use GPS to track their vehicles. Figure 4.3 demonstrates LVMPD jurisdictional boundary definitions.

The outer box is called the area command. Area command is then divided into Sectors. Each sector is again divided into Beats. Each beat is divided and numbers are assigned. In each sector, multiple CIT officers are allocated. Officers must remain in their assigned sectors. However, they can be in any beat within their sector.

All the events are recorded in CAD along with audio files. 90% to 95% of all information, such as time stamp and types of incident, is recorded in the CAD system. However, there is no direct link between crash reports and CAD data. Typical duration of LVMPD involvement in traffic incidents of three types are as follows (excluding the time agency take to reach the scene):

- PDO (property damage only) - 45 minutes
- Injury - 60-90 minutes
- Fatal - 4 hours

4.3.2 LVMPD Dispatch Center

There are two types of officials at the dispatch center Call takers and Dispatchers.

Call Takers

The responsibilities of a Call-taker is as follows:

- Attending all incoming calls: emergency 911, Non-Emergency 311, and PBX filtered calls.
- Transferring the calls to NHP, North Las Vegas, and Henderson police departments when needed.
- Log in data.

Call takers must abide by the telephone service factor (TSF) which indicates the maximum delay to attend the call is 10 seconds. If a call comes from the Clark County area, based on the incident, they will put the 911 calls in conference with fire, PD, ambulance response, county roads, public works, etc. This is done by a click provided on the computer screen. The screen contains the icons with the contact numbers and radio channels to each agency. Hot line is also provided to communicate with other agencies. LVMPD CAD may not have to get the call (depending on the type of incident). Therefore, the call could be forwarded straight to the appropriate agency. Call takers are provided with two incident recording screens containing the number of incidents to be attended, police officers at the incidents being served, and a map showing the location of the police officers. The call takers job is done once the 911 call and transferring to the appropriate agencies to specific incident is done.

Dispatchers

The dispatchers are responsible to communicate with other agencies to inform them of incidents or other information. They do not, however, have access to other agencies CAD. When calls are transferred to fire department, it goes straight to the dispatcher. They do not have to wait (automatic drop down line). Number of dispatchers depends on the number of radio channels.

Resources

- Eight regular patrol channels (black and white cars). Enterprise areas of command are based on geographic location.
- One channel: driver license, registration, stolen vehicles, regulation plates.
- Multiple Channels: resident officers, Laughlin, Mount Charleston.

There is one dispatcher per channel. The software automatically routes the call to the appropriate area. The dispatchers are responsible for sending an officer to the scene. The number of officers and distribution depends on the area and time of day. There are 250 areas in Las Vegas. The police officer will contact the dispatcher (not the call taker) via radio once arrives at the scene. The officer normally reports information about the incident status to the dispatcher. Officers will act according to the Incident command system (ICS). ICS will send a command post up to the officer arrived on the scene.

Computer Aided Dispatch (CAD) System

The 911 calls are programmed to lift automatically at one of the call takers. Call taking process is distributed among the call takers (Load shedding). In the CAD software, the incident number will be automatically assigned, also, the longitude and latitude if it is a landline call or nearest cell tower if it is a cell-phone call, information will be automatically extracted once the call is received. Operators can determine redundancy of calls for a certain incident by the location information obtained when the call is made. Fields such as type of the incident, address, location and a specific code for the incident will be filled by the call taker. The call taker will assign a code to a certain accident indicating the type and severity of accident depending on the information obtained from the caller. The system will determine the priority of the incident according to the code assigned by the operator (call taker). More than one call maybe received for one incident which leads to multiple inputs for the same incident.

Depending on the information the operators obtain, the codes assigned to the same accident may vary. In this case, the operators go by the code from the first call received. The officer uses and has access to the same screen as the operator where information can be added and edited in the system. If the multiple call takers record the same incident, call takers will communicate themselves and decide which ones to be dropped. This has to be done manually since the software does not have the ability to recognize similar sources. Only one dispatcher is responsible for a certain area which eliminates any confusion regarding multiple inputs for an incident. Incidents are organized by the time they were received as well as location.

Same software is installed in all the computers in dispatch center, but the access to the software is restricted based on the duties of the personnel (mobile police, call takers, dispatchers) Police from the scene will use radio to communicate with the dispatcher. If the officer has a computer in the vehicle, then details of the incident can be entered in the same CAD software.

LVMPD will take care of the incident until it clears and maintains the information of the incident given only by LVMPD police officers at the scene for 60 days. Crime analysts, area command, traffic departments will keep the information of the incident. They compile the data for certain areas. The Press and Information Office (PIO) is responsible for tracking the process and in charge of informing the public. PIO's office sources are: RTC, LVMPD, NDOT, and NHP.

4.4 Nevada Highway Patrol- NHP Meetings Summary

Unlike LVMPD, NHP does not differentiate between a call taker and a dispatcher. In other words, the caller is also the dispatcher. NHP can be informed about an incident either via an emergency call transfer from LVMPD (911) or directly via FAST cameras; either way, NHP does not inform 911 with the occurrence of an accident. NHP dispatch center and FAST operators share the same venue and work side by side to monitor proper operation of the freeway. Therefore, NHP dispatchers have direct access to FAST cameras and can view the

status of the freeway at all times. If they observe an accident in the video, they act immediately to clear it. In other cases, the FAST software displays red at a particular location when an accident is suspected using flow sensors. Then, cameras are pointed towards that location in order to view the accident. If FAST cameras are not available, then an NHP officer drives to the incident location.

There are NHP dispatch centers at the following locations:

- Elko
- Carson City
- Las Vegas

All dispatch centers can communicate with each other. They also use a shared data base. Data is available in the form of crystal reports. NHP is more “proactive” than “reactive.” Dispatchers (same as call takers) check on troopers every 30 minutes. When a trooper is needed to be at a certain incident scene, a general message will be broadcasted. The closest unit to the scene will get on the radio (800MHz is used) and communicate with the dispatcher. Radio has a higher priority than calls. In general, ambulance is called in most cases. Once the troopers are on the incident scene, they make the decision of whether a certain lane should be closed or not. Officers have an IPac on which they document everything. Then they download it onto the computers. They do not have access to the CAD system from the IPac.

Dispatchers

Dispatchers are trained by going through a 5-6 weeks class then 5-6 months hands-on training.

CAD Software

CAD software identifies duplicate incident entries based on location within 0.5 miles difference and time. There is no GIS display.

Troopers

They may ask the Police Department (PD) for help in traffic control.

NHP Jurisdiction

NHP jurisdiction is off ramp up to the first intersection.

NHP Resources

There are 2 squads, 4 - 14 troops each. One is scheduled to work LV1, the other LV2. Currently, there are no motorcycle units; however, bringing them back is under discussion.

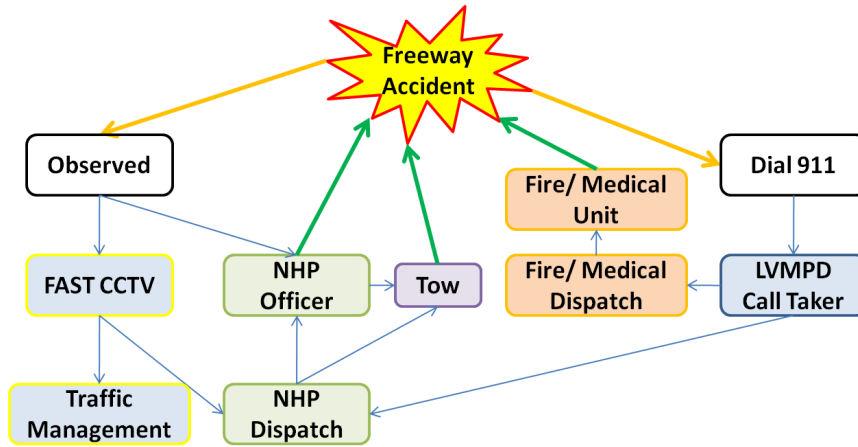


Figure 4.4: General model for freeway incident response

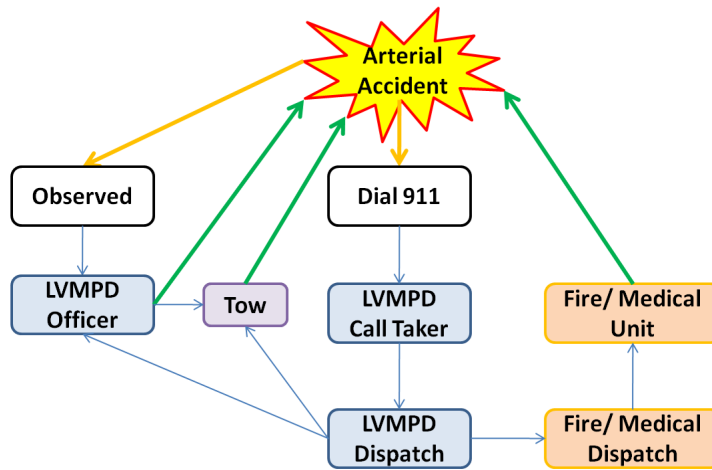


Figure 4.5: General model for arterial incident response

4.5 Meetings Summary

Figure 4.4 shows the general model for freeway incident response. Figure 4.5 shows the general model for arterial incident response.

There are two ways to detect a freeway incident: by receiving an emergency call (911) or by observation. Emergency calls are received by call takers at the dispatch center at LVMPD; then they forwarded to the NHP dispatch center, since freeway is NHP's jurisdiction. NHP then obtains more information about the incident and communicates with other agencies, if needed. If the caller, however, asked for fire or medical, then LVMPD call takers transfers the call to Fire dispatch. With regards to detection by observation, there are two ways this can be accomplished: FAST CCTVs or NHP officer. Either case, the observer directly communicates with NHP Dispatch in order to properly manage the incident.

Similarly, an arterial incident can also be observed either by a 911 call or by observation. Observation, however, can only be done through an officer since FAST CCTVs do not currently cover arterial systems. In both cases, the incident is reported to LVMPD dispatch where incident verification is done in order to extract more information about the nature of the in-

cident. LVMPD dispatch, then, determines what other agencies need to be dispatch to the scene as well such as Tow or Fire.

Chapter 5

Surveys

Before the TIM program was implemented, all the agencies involved were given a survey questionnaire regarding the different aspects of incident management (the “before” survey). After the TIM program was completed, the agencies were surveyed once more (the “after” survey). This chapter presents the questions and the results obtained for the “before” survey. There were not enough responses to the “after” survey to produce any significant results. The questions of the “after” survey are presented in the appendix. Because these surveys are vital in understanding the “human factor” involved incident management, it is recommended that guidelines be provided by NDOT in the development of performance metrics for these surveys.

5.1 “Before” Survey

This survey was given to selected TIM members as an assessment of the incident management system in the Las Vegas area prior to the formation of TIM. The selection spanned personnel from several agencies Fire, Emergency Management (EM), Coroner’s Office, Regional Flood Center, Freeway and Arterial System of Transportation (FAST), Police Department (PD), Nevada Department of Transportation (NDOT), Nevada Highway Patrol (NHP), and Regional Transportation Commission (RTC). The sections of the survey are General, Incidents, Incident Response, Incident Management Legislation, Incident Technology and Equipment, Incident Management, Keeping Track of Incidents, and Incident Management Benefits.

In this section, the survey questions are presented followed by the results and conclusions.

5.1.1 Survey Questionnaire

General

1. Name
2. Job Title

3. Agency
4. Mailing Address
5. Phone
6. Fax
7. Email
8. Please identify the geographical and/or jurisdictional areas to which your answers to this survey apply (i.e., all freeways within region or freeways only within certain counties) for your area of geographical or jurisdictional coverage.

Incidents

1. How does your agency define an incident?
2. Rate the prevalence of the following types of incidents within your jurisdiction, using 1 for the least prevalent and 5 for the most prevalent.
 - (a) Single vehicle crash
 - (b) Disabled/abandoned vehicle
 - (c) Multi-vehicle crash
 - (d) Hazardous material spill
 - (e) Debris on roadway
 - (f) Weather related debris on roadway
3. Rate the prevalence of the following types of secondary incidents that occur within the Las Vegas area, using 1 for the least prevalent and 5 for the most prevalent
 - (a) Collision
 - (b) Disabled Vehicle
 - (c) Other

Incident Response

1. What is your agency's role in incident clearance and management?
2. What other agencies does your agency interact with in case of an incident?
3. How would you rate the comprehensiveness of collaboration between your agency and the agencies you listed above, using 5 for very comprehensive and 1 for least comprehensive?
4. How would you rate the effectiveness of collaboration between your agency and the agencies you listed above, using 5 for very comprehensive and 1 for least comprehensive?
5. Has your agency instituted a new incident management/clearance program/strategy or upgraded a current program/strategy aimed at increasing collaboration between other relevant agencies?

Incident Management Legislation

1. Does your jurisdiction have a “quick clearance” law which requires drivers of motor vehicles who are involved in a property-damage only crash to move their damaged vehicle from travel lanes to alternate locations such as the shoulder?
 - (a) Unknown if legislation exists
 - (b) No existing or proposed legislation
 - (c) Bill currently proposed
 - (d) Yes
2. Does your state have a “move it” law which requires incident clearance patrols to move vehicles that are involved in property-damage only crashed to alternate locations such as the shoulder?
 - (a) Unknown if legislation exists
 - (b) No existing or proposed legislation
 - (c) Bill currently proposed
 - (d) Yes
3. If there is other legislation within your jurisdiction aimed at facilitating incident management, please cite them here.
4. Does your jurisdiction have legislation that protects incident management responders from liability when moving vehicles involved in an incident?
 - (a) Yes
 - (b) No
 - (c) Unknown

Incident Technology and Equipment

1. How does your agency detect incident? Rate the performance of the different technologies that you currently use. Check “Technology Planned” if your agency does not currently utilize the technology but is planning to implement it. (1 worst- 5 best)
 - (a) Traffic Cameras
 - (b) Automated incident Detection (sensors)
 - (c) Highway Patrol Communication
 - (d) Cellular Phone (public)
 - (e) Call box
 - (f) Other

2. Once an incident is detected, how is the incident verified? Rate the performance of the different technologies/methods that you currently use. Check "Technology Planned" if your agency does not currently utilize the technology but is planning to implement it. (1 worst - 5 best)
 - (a) Traffic Cameras
 - (b) Automated incident Detection (sensors)
 - (c) Highway Patrol Communication
 - (d) Cellular Phone
 - (e) Call box
 - (f) By Air
 - (g) Dispatched Personnel
 - (h) Other
 - (i) N/A

3. How is communication accomplished between your agency and the other incident responder agencies? Check all that apply and rate the performance of the different technologies using 5 for the least and 1 for the worst. Check "technology Planned" if your agency does not currently utilize the technology but is planning to implement it. (1 worst - 5 best)
 - (a) Cellular phone
 - (b) Internet/Computer
 - (c) Radio with dedicated frequency
 - (d) Radio without dedicated frequency
 - (e) Other

4. What type of Intelligent Transportation Systems (ITS infrastructure does your agency use to handle incident management? Check all that apply. (1 implemented, 2 planned, 3 not planned, 4 no longer used)
 - (a) Traffic Cameras
 - (b) Dynamic message signs
 - (c) Computer Aided Dispatch (CAD)
 - (d) Automated Incident Detections (Sensors)
 - (e) Traffic Management Center
 - (f) Automated Vehicle Locators (AVL)
 - (g) Highway Advisor Radio (HAR)
 - (h) Dynamic Lane Designation
 - (i) Other
 - (j) N/A

5. What equipment is available to your agency to facilitate the clearance of a non-hazardous incident? Check all that apply.
- (a) Heavy-duty tow truck
 - (b) Sweeper
 - (c) Empty box trailer
 - (d) Air cushion recovery
 - (e) Crane
 - (f) Debris recovery vehicle
 - (g) Empty tanker truck
 - (h) Empty box trailer
 - (i) Empty livestock trailer
 - (j) Dump truck
 - (k) Other

Incident Management

1. Does your agency have a route diversion/alternate route plan? (1 yes - 2 No)
2. If your agency has a route diversion/alternate plan, rate the effectiveness of the following route diversion tools used by your agency, using 5 for the most effective and 1 for the least effective. (1 very ineffective - 5 very effective)
- (a) Ramp Metering
 - (b) Dynamic Message sign alerts
 - (c) Arterial signal control
 - (d) Highway advisory radio (HAR) alerts
 - (e) Lane Closure systems
 - (f) Other
3. What are the components of your incident management strategies? Check all that apply (1 implemented, 2 planned, 3 not planned, 4 no longer used)
- (a) Route diversion
 - (b) Notifications through DMS
 - (c) Collaborative agreements giving agencies authority to move vehicles from the ROW
 - (d) Major equipment for vehicle removal
 - (e) Agreement with towing companies
 - (f) collaborative agreements for information sharing
 - (g) Other

(h) N/A

4. What problems have you encountered with implementation? Check all that apply

- (a) Lack of political support
- (b) Lack of public awareness
- (c) Lack of coordination between agencies
- (d) Lack of public support
- (e) Lack of funding
- (f) other

Keeping Track of Incidents

1. Indicate what kind of data your agency keeps on record and how long it is stored? (0-30 days, 31-60 days, 61-90 days, more than 90, days not kept)

- Phone calls
- video recordings
- sensor readings
- Other:

2. Indicate what information is collected about each incident by your agency? (Check all that apply.)

- Roadway name
- Location/Cross street name
- block number
- Detector station number
- Geographic location (lat/log)
- Location of lanes blocked
- Incident type
- Incident source
- Current status of incident
- Time incident was detected
- Time incident was verified
- Source of incident verification
- Time response vehicles arrived on scene
- Are arrivals recorded individually
- Are arrivals recorded collectively
- Types of vehicles on scene

- Time response vehicles left scene
 - Time incident was cleared from scene
 - Moved to shoulder
 - Responders depart
 - Removed from roadway
 - Other
 - Time normal traffic was restored
 - Roadway surface conditions
 - Light condition
 - Weather condition
 - Injuries present
 - Number of vehicles involved
 - Type of vehicles involved
 - Incident severity
 - Others
3. Indicate what other performance measures you are not collecting but you think would be beneficial for you to know as they relate to the performance of your incident management system? If any, what are they and how would you measure them?
4. Indicate what agencies/organizations have access to the data that is collected by your agency. Check all that apply (Primary, Secondary Stakeholders)
- Regional Transportation Commission of Southern Nevada (RTC)
 - FAST
 - State Transportation Agencies
 - Nevada Department of Transportation (NDOT)
 - District 1, District Engineer
 - District 1, Traffic Operations
 - State Public Safety/Emergency Services
 - Nevada Highway Patrol
 - Emergency Management
 - Federal Agencies
 - National Oceanic and Atmospheric Administration (National Weather Service)
 - Emergency Management Agencies
 - Clark County Emergency Management
 - City of Henderson Emergency Management
 - City of Las Vegas Emergency Management
 - City of North Las Vegas Emergency Management

- RTC Emergency Management Plan
- Local Public Safety/Emergency Services Agencies
- City of Henderson Police/Fire Departments
- City of Las Vegas Fire Department
- City of North Las Vegas Police/Fire Departments
- Metropolitan Police Department (Serves Clark County and City of Las Vegas)
- Clark County Fire Department
- Ambulance Services
- Public Involvement/PIO's Media

- Regional Transportation Commission of Southern Nevada (RTC)
- MPO
- Capital Projects
- State Agencies
- Nevada Agency for Nuclear Projects
- State of Nevada Information Technology
- Nevada Department of motor vehicles (CVO)
- State Transportation Agencies
- Arizona Department of Transportation
- CALTRANS District 8
- Nevada Department of Transportation (NDOT)
- District 1, Engineering
- District 2, Traffic Operations
- District 2, Engineering
- District 3, Traffic Operations
- District 3, Engineering
- Highway safety Engineering (HQ)
- ITS (HQ)
- Rural Transit (HQ)
- Rail Safety (HQ)
- Planning (HQ)
- CVO(HQ)
- Nevada office of traffic safety
- Federal Agencies
- U.S.Department of energy office of national Transportation
- Bureau of Indian Affairs

- Environmental Protection Agency
- U.S. Department of Energy - Yucca Mountain
- U.S. Forest Services (Spring Mountain Ranger District)
- Federal Transportation Agencies
- Federal Highway Administration (FHWA)
- Nevada Division Office
- Western Resource Center
- Federal Motor Carrier safety administration
- Federal transit administration (FTA)
- City/County/Local Agencies
- City of Henderson Traffic Engineering/Public Works
- City of Las Vegas Traffic Engineering/Public Works
- City of North Las Vegas Transportation Services/Public Works/Roadway Ops
- Clark county traffic management/public works
- Clark county maintenance management/public works
- Clark county Department of Aviation
- Clark County Coroner's office
- Nye County Public works
- City of Mesquite Public Works
- Clark County Design Engineering
- Esmeralda County Public Works
- Mineral County Public Works
- Lander County Road and Bridge department
- McCarran Airport Planning (Clark County Dept. of Aviation)
- Transit Agency (RTC)
- Citizens Area Transit (CAT)
- Local Public Safety/Emergency Services
- City of Boulder City Police Department
- Landers County Sheriff's Office
- Las Vegas Metropolitan Police (IT Bureau)
- Las Vegas Metropolitan Police (Automation Policy and Planning)
- Public Utilities
- Nevada Power (Telecommunications)
- Southwest Gas

- Southern Nevada Water Authority (SNWA)
 - Academic Institutions
 - University of Nevada, Las Vegas (UNLV) Transportation Research Center
 - UNLV College of Engineering
 - Railroad
 - Union Pacific Railroad
 - Private Sector
 - AAA Nevada
 - California State Automobile Association
5. Indicate if you integrate or compare your information with other agencies? If so, indicate when, how often, and how this is done.
6. In general, what are your findings when you compare information with other agencies?

Incident Management Benefits

1. How is information (benefits and costs) of your incident management program communicated to decision makers? Rate the effectiveness of each form of communication using 5 for the most effective and 1 for the least effective.
 - (a) Personal communication
 - (b) Electronically (internet, e-mail, etc)
 - (c) Print (brochure, newsletter, magazine. Etc.
 - (d) Other
2. How is information (benefits and costs) of your incident management program communicated to the public? Rate the effectiveness of each form of communication using 5 for the most effective and 1 for the least effective.
 - (a) Personal communication
 - (b) Electronically (Television, internet, e-mail, etc)
 - (c) Print (brochure, newsletter, magazine. Etc.
 - (d) Public Meetings
 - (e) Other
3. Please indicate any additional information/data that you believe is valuable in accessing the benefits and costs of incident management clearance.

Additional information

Please give us any comments, suggestion, or additional information you feel will help in preparing the Incident Management Guidelines for Clark County

5.1.2 Results

Personnel who assisted in filling out the survey were from Clark County (CC) Fire, Emergency Management (EM), Coroner, Regional Flood Center (RFC), FAST, Police Department (PD), NDOT, NHP, and RTC. The following is a compilation of the obtained results.

Incidents

How does your agency define incidents?

- **CC Fire:** Any time a Fire unit gets dispatched by the Fire Alarm Office (FAO) and goes en-route it is considered an incident and an incident number is created. An incident can be an emergency (fire, medical call, or traffic accident) or non-emergency (public assist, or information gathering), which is still given an incident number.
- **CC EM:** An occurrence that requires intervention by a public safety agency to resolve.
- **CC Coroner:** The need for our services or call for service.
- **CC Regional Flood Center:** Severe rainstorm and flooding in washes and on roadways.
- **FAST:** An event that has the potential to cause nonrecurring congestion to occur or otherwise exacerbate recurring congestion.
- **Henderson PD:** Any reported event.
- **LVMPD:** Any event that requires law enforcement involvement, according to Captain Tom Conlin (LVMPD, retired).
- **NDOT:** Any non-recurring event that affects traffic on roadways maintained by NDOT, whether or not NDOT goes to the scene.
- **NHP:** An incident is anything that would require a law enforcement presence in order to ensure public safety.
- **RTC:** Any significant event that impacts transportation services or affects security issues. This includes traffic crashes that involve a transit vehicle, criminal activity at traffic stops or on the transit vehicles, and general breach of security.

Rate the prevalence of the following types of incidents within your jurisdiction, using 1 for the least prevalent and 5 for the most prevalent.

	Fire	EM	Crn	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Single vehicle crash	5	5	2	1	3	3	5	1	5	1
Disabled/abandoned vehicle	1	2	1	1	4	3	3	3	5	1
Multi-vehicle crash	5	2	3	2		5	5	5	4	3
Hazardous material spill	3	1	2	4	1	1	1	1	2	1
Debris on roadway	1	2	1	3	4	2	1	2	5	1
Weather related debris on roadway	1	2	1	5	2	1	1	1	1	1

Rate the prevalence of the following types of secondary incidents that occur within the Las Vegas area, using 1 for the least prevalent and 5 for the most prevalent.

	Fire	EM	Crn	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Collision	5		2	1	3	3	5	4	5	1
Disabled Vehicle	1		1	1	3	3	1	2	5	1
Other			1	1				5		

Incident Response

What is your agency's role in incident clearance and management?

- **CC Fire:** Once an incident scene is stabilized, CC Fire either lets the civilian call a tow truck or lets the police agency on scene (Metro, or highway patrol) contact a tow vehicle.
- **CC EM:** None.
- **CC Coroner:** Removal of decedent from scene.
- **CC Regional Flood Center:** Incident clearance by means of network reporting information and flood flow advisement. This agency does not have a field presence.
- **FAST:** The main focus is management by assisting the NHP and the Freeway Service Patrol (FSP) in responding to incidents. FAST also provides traveler information, using dynamic message signs and CCTVs.

- **Henderson PD:** To get the roadways open again for use, Henderson PD reports the incident, preserves any evidence, and generates incident report. This process can take from a few minutes to hours. For a minor PDO, the cars are moved off the roadway as quickly as possible. For major crash with one or more fatality the time increases according to the amount of investigation needed and the involvement by the county coroner. At an incident with a fatality, the Henderson PD does not call the coroner until almost done with the investigation, including making diagrams of the area, taking pictures, and filling out reports. This process usually takes about 90 minutes. When the offices in charge on-scene estimates that they are about 30 minutes from being done with the investigation, they put in a call to get the coroner to the scene. This is done so that the coroner is not standing around waiting for them to finish the investigation. In some instances, the Fire Department is called out to extricate the body; however, Fire does not always stay on scene during the investigative process.
- **LVMPD:** On freeways, LVMPD has little to no role in incident clearance unless NHP asks for help. In 2006, LVMPD handled one fatal crash for NHP because one of their employees was the at-fault driver. On arterials, Metro is responsible for accident investigation, accident clearance, and traffic enforcement.
- **NDOT:** Usually, maintenance staff are called out to an incident to provide traffic control, clean up debris, manage clean up of spills, and repair the roadway.
- **NHP:** The NHP is the primary agency in charge of incident clearance. They provide case managers, divert traffic to ensure public safety, clear the roadway, and investigate the incident.
- **RTC:** RTC is mainly a resource during an incident. They are tasked with providing bus service to emergency responders. During a crash involving a transit vehicle, RTC sends out an investigative unit.

What other agencies does your agency interact with in case of an incident?

- **CC Fire:** This agency interacts with the law enforcement agency in charge of the roadway. The Metropolitan Police Department (Metro) Nevada Highway Patrol, North Las Vegas Police, UNLV Police, or the School District Police. They also interact with the private ambulance companies, which is either South West Medical, or American Medical Response (AMR). If there is a gas spill that needs to be contained, they call on the Department of Public Works. Also, they interact with the private tow truck companies.
- **CC EM:** According to this agency, there are too many agencies to list
- **CC Coroner:** The County Coroner interacts with all first responders: Police, Fire, hospitals, the Health District, OSHA, FAA, and so forth.
- **CC Regional Flood Center:** This agency interacts with any of the public entities: City, County, NDOT, NHP, Police, and Fire (both Public Works and Emergency Management).
- **FAST:** FAST interacts with NDOT including the Freeway Service Patrol (FSP) and NHP.

- **Henderson PD:** This police department interacts with the Henderson Fire Department, LVMPD, NHP, contracted towing companies, Public Works, and Traffic.
- **LVMPD:** All law enforcement, EMS, and fire services. This agency works with REACT, NDOT, Clark County Public Works, City of Las Vegas Public Works, Coroner, UMC Trauma, taxi cab authorities, and the CAT bus in the Las Vegas valley. In rural areas, this agency works with the Bureau of Land Management (BLM), Tribal Police, and so forth.
- **NDOT:** This agency works with law enforcement, the Fire Department, the Department of Public Works, and other agencies as needed.
- **NHP:** The NHP interacts with all public safety agencies, NDOT, FAST, the counties of Nevada, the National Guard. Basically, they work with anyone that they feel need to be contacted during an incident.
- **RTC:** This agency interacts with law enforcement, the Fire Department, medical units, and emergency managers.

How would you rate the comprehensiveness of collaboration between your agency and the agencies you listed above, using 5 for very comprehensive and 1 for least comprehensive?

	Fire	EM	Crnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Comprehensiveness of collaboration	5	5	4	3	4	3	5	5	4	3

How would you rate the effectiveness of collaboration between your agency and the agencies you listed above, using 5 for very comprehensive and 1 for least comprehensive?

	Fire	EM	Crnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Comprehensiveness of collaboration	5	5	4	4	4	3	5	5	4	4

Has your agency instituted a new incident management/clearance program/strategy or upgraded a current program/strategy aimed at increasing collaboration between other relevant agencies?

1. **FAST:** Yes
2. **NDOT:** No
3. **RTC:** Members of RTC attended seminar called “Connecting Communities,” which is a workshop aimed at showing the emergency responder what the capabilities of the other agencies are and how to work together during an incident.

Incident Management Legislation

Does your jurisdiction have a “quick clearance” law which requires drivers of motor vehicles who are involved in a property-damage only crash to move their damaged vehicle from travel lanes to alternate locations such as the shoulder?

	Fire	EM	Crnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Unknown if legislation exists		x			x					
No existing or proposed legislation	x			x						
Bill currently proposed							x			
Yes						x		x	x	x

Does your state have a “move it” law which requires incident clearance patrols to move vehicles that are involved in property-damage only crashed to alternate locations such as the shoulder?

	Fire	EM	Crnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Unknown if legislation exists		x			x					
No existing or proposed legislation	x			x		x		x		
Bill currently proposed							x			
Yes									x	

If there is other legislation within your jurisdiction aimed at facilitating incident management, please cite them here.

- **CC Fire:**
- **CC EM:**
- **CC Coroner:**N/A.
- **CC Regional Flood Center:**None.
- **FAST:**
- **Henderson PD:** None that this agency is aware of.
- **LVMPD:** We are not in support of the above. PDO crashes often turn out to be injury crashes later, and they also can be staged for insurance fraud. We don't like moving vehicles until a trained investigator takes control.

- **NDOT:** There is no existing legislation.
- **NHP:** Do not know.
- **RTC:** Do not know.

Does your jurisdiction have legislation that protects incident management responders from liability when moving vehicles involved in an incident?

- **CC Fire:** No
- **CC EM:** Unknown
- **CC Coroner:** Unknown
- **CC Regional Flood Center:**No
- **FAST:** Unknown
- **Henderson PD:** No
- **LVMPD:**Unknown
- **NDOT:** Unknown
- **NHP:** Unknown
- **RTC:** Do not know

Incident Technology and Equipment

How does your agency detect incident? Rate the performance of the different technologies that you currently use. Check “Technology Planned” if your agency does not currently utilize the technology but is planning to implement it. (1 worst- 5 best)

	Fire	EM	Crnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Traffic Cam-eras					5			1		
Automated incident Detection (sensors)					Planned			1		
Highway Patrol Com-munication					4			Planned		
Cellular Phone (pub-lic)					3			3		
Call box					2			3		
Other		Police						Police		Police

Once an incident is detected, how is the incident verified? Rate the performance of the different technologies/methods that you currently use. Check “Technology Planned” if your agency does not currently utilize the technology but is planning to implement it. (1 worst - 5 best)

	Fire	EM	Crnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Traffic Cam-eras						5		1		
Automated incident Detection (sensors)					Planned			5		
Highway Patrol Com-munication					4			3		
Cellular Phone					3			3		
Call box					1			1		
By Air					1			4		
Dispatched Personnel					3			4		
Other										
N/A		x								

How is communication accomplished between your agency and the other incident responder agencies? Check all that applies and rate the performance of the different technologies using 5 for the least and 1 for the worst. Check “technology Planned” if your agency does not currently utilize the technology but is planning to implement it. (1 worst - 5 best)

	Fire	EM	Crnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Cellular Phone (pub-lic)	3	5	5	4	3	2	4	5	5	
Internet/ Computer	5	5	3	4	3	3	3	3		
Radio with Dedicated Frequency	3	3	3	5	1	4	Planned	1		
Radio without Dedicated Frequency	5	3	3		1	3	1	1		
Other	5			5f2fnhp						

What type of Intelligent Transportation Systems (ITS infrastructure does your agency use to handle incident management? Check all that apply. (1 implemented, 2 planned, 3 not planned, 4 no longer used)

	Fire	EM	Crnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Traffic Cameras					1			2		
Dynamic message signs					1			2		
Computer Aided Dispatch (CAD)								2		
Automated Incident Detections (Sensors)					2			2		
Traffic Management Center					1			2		
Automated Vehicle Locators (AVL)					2			2		
Highway Advisor Radio (HAR)					3			1		
Dynamic Lane Designation					3			2		
Other										
N/A										

What equipment is available to your agency to facilitate the clearance of a non-hazardous incident? Check all that apply.

	Fire	EM	Cmr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Heavy-duty tow truck	x					x	x	x		
Sweeper	x					x	x	x		
Empty box trailer								x		
Air cushion recovery	x							x		
Crane	x							x		
Debris recovery vehicle	x							x		
Empty tanker truck								x		
Empty box trailer								x		
Empty live-stock trailer								x		
Dump truck	x							x		
Other						x		x	x	

Incident Management

Does your agency have a route diversion/alternate route plan? (1 yes - 2 No)

- **CC Fire:**
- **CC EM:** No.
- **CC Coroner:**
- **CC Regional Flood Center:**
- **FAST:** No.
- **Henderson PD:**
- **LVMPD:**
- **NDOT:** No.
- **NHP:**
- **RTC:** Yes.

If your agency has a route diversion/alternate plan, rate the effectiveness of the following route diversion tools used by your agency, using 5 for the most effective and 1 for the least effective. (1 very ineffective - 5 very effective)

	Fire	EM	Cmnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Ramp Metering										
Dynamic Message sign alerts										
Arterial signal control										
Highway advisory radio (HAR) alerts										
Lane Closure systems										
Other										

What are the components of your incident management strategies? Check all that apply (1 implemented, 2 planned, 3 not planned, 4 no longer used)

	Fire	EM	Cmnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Route diversion					2			2		1
Notifications through DMS					1			2		1
Authority to move vehicles from the ROW								3		3
Major equipment for vehicle removal					1			1		
Agreement with towing companies										1
Information sharing								3		1
Other										
N/A	x									

What problems have you encountered with implementation? Check all that apply

	Fire	EM	Cmnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Lack of political support										
Lack of public awareness					x					
Lack of coordination between agencies					x			x		
Lack of public support										
Lack of funding										
other								x		

NDOT: Lack of media understanding.

Keeping Track of Incidents

Indicate what kind of data your agency keeps on record and how long it is stored? (0-30 days, 31-60 days, 61-90 days, more than 90, days not kept)

	Fire	EM	Cmnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Phone calls			5	5	5	4	5		4	5
video recordings			5	4	5	4	5	5	4	1
sensor readings			5	4	4	5	5	5		5
Other:			4							

Indicate what information is collected about each incident by your agency? (Check all that apply.)

	Fire	EM	Crnr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Roadway name	x			x		x	x		x	
Location/Cross street name	x			x		x	x		x	
Block number	x					x	x		x	
Detector station number				x						
Geographic location (lat/log)	x			x		x	x		x	
Location of lanes blocked	x						x		x	
Incident type	x		x	x		x	x		x	
Incident source			x	x		x	x		x	
Current status of incident	x			x		x	x		x	
Time incident was detected	x			x		x	x		x	
Time incident was verified	x		x			x			x	
Source of incident verification			x			x			x	
Time response vehicles arrived on scene	x		x			x	x		x	
Are arrivals recorded individually	x		x			x	x		x	
Are arrivals recorded collectively	x									
Types of vehicles on scene	x		x			x			x	
Time response vehicles left scene	x					x	x		x	
Time incident was moved to shoulder									x	
Time responders depart	x					x			x	
Incident clearance time									x	
Recovery time									x	
Roadway surface conditions						x	x		x	
Light condition	x					x	x		x	
Weather condition	x		x	x		x	x		x	
Injuries present	x		x			x	x		x	
Number of vehicles	x		x			x	x		x	
Type of vehicles involved	x		x			x	x		x	
Incident severity						x	x		x	
Others									x	

Indicate what other performance measures you are not collecting but you think would be beneficial for you to know as they relate to the performance of your incident management system? If any, what are they and how would you measure them?

- **CC Fire:**
- **CC EM:**
- **CC Coroner:**
- **CC Regional Flood Center:** This agency uses streaming video to verify incidents. They do not know flood conditions on the roadways in order to better monitor roadways. FAST CCTV's would be helpful.
- **FAST:**
- **Henderson PD:** This police department acquires surveillance videos from stores in the area, if the incident was recorded. They would like to know the capabilities of the cameras on the arterials and if video can be recorded there.
- **LVMPD:**
- **NDOT:**
- **NHP:**
- **RTC:**

Indicate what agencies/organizations have access to the data that is collected by your agency. Check all that apply (Primary, Secondary Stakeholders)

Primary Stakeholders

	Fire	EM	Cmr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
RTC		x		x		x				
FAST		x		x		x				
STA		x				x				
NDOT		x	x	x		x	x		x	
Dist 1, DE		x		x		x				
Dist 1, TO		x	x			x				
SPS/ES		x				x				
NHP	x	x	x	x		x	x			
EM	x	x	x	x		x				
FA		x				x				
NOAA		x		x		x				
EM		x				x				
CCEM	x	x	x	x		x				
CHEM		x	x	x		x				
CLVEM	x	x	x	x		x				
CNLVEM	x	x	x	x		x				
RTC EMP		x	x	x		x				
LPS/ESA		x				x				
CHP/FD		x		x		x				
CLVFD	x	x		x		x				
CNLVP/FD	x	x		x		x				
MPD	x	x		x		x	x			
CCFD	x	x		x		x				
AS	x	x				x				
PIO's Media	x	x		x		x	x			

Secondary Stakeholders

	Fire	EM	Cmr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
RTC		x		x		x				
MPO		x		x		x				
CP		x		x		x				
SA		x				x				
NANP		x		x		x				
SNIT		x		x		x				
NDMV(CVO)		x		x		x				
STA		x		x		x				
ADT		x	x	x		x				
CALTRANS Dist 8		x		x		x				
NDOT		x	x	x		x				
Dist 1, Eng		x				x				
Dist 2, Traffic Operations		x				x				
Dist 1, Eng		x				x				
Dist 2, TO		x				x				
Dist 3, Eng		x				x				
HSE (HQ)		x	x			x				
ITS (HQ)		x				x				
Rural Transit (HQ)		x	x			x				
Rail Safety (HQ)		x				x				
Planning (HQ)		x				x				
CVO(HQ)		x				x	x			
NOTS		x	x		x					
FA		x				x				
U.S.DEONT		x	x			x				
BIA		x	x			x				
EPA		x	x			x				
U.S.DE - Yucca Mountain		x				x				
U.S.FS(SMRD)		x				x				
FTA		x				x				
FHWA		x	x			x				
NDO		x	x			x				
WRC		x				x				
FMCS		x				x				
FTA		x				x				
C/Cty/Loc Ag		x				x				
CHTE/PW		x				x				
CLVTE/PW		x				x	x			
CNLVTS/ PW/ Roadway Ops		x				x				
CCTM/PW		x				x	x			
CCMM/PW		x				x				

	Fire	EM	Cmr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
CCDA		x				x				
CCCO		x				x				
NCPW		x				x				
CMPW		x				x				
CCDE		x				x				
ECPW		x				x				
MCPW		x				x				
LCRBD		x				x				
MAP (CCDA)		x				x				
RTC		x				x				
CAT		x	x			x				
LPS/ES		x				x				
CBCPD		x				x				
LCSO		x				x				
LVMPD (ITB)	x	x				x	x		x	
LVMPD (APP)	x	x				x	x		x	
PU		x				x				
NVE (Telcom)		x				x				
SG		x				x				
SNWA		x				x				
Academic Institutions		x				x				
UNLV, TRC		x				x	x		x	
UNLV Eng		x				x	x		x	
Railroad		x				x				
UPR		x				x				
PS		x				x				
AAA NV		x				x				
CSAA		x				x				

Indicate if you integrate or compare your information with other agencies? If so, indicate when, how often, and how this is done.

- **CC Fire:** This agency sends a monthly report to the National Incident Fire Reporting System (NIFRS) via the Nevada State Fire Marshall office, so that statistical information can be shared on a state-wide and national level. They send a yearly report to the National Fire Protection Association (NFPA). They also share a database with the City of Las Vegas Fire and Rescue and with the City of North Las Vegas Fire Department, who can retrieve any information as needed. Most information is shared electronically or by means of a survey.
- **CC EM:**
- **CC Coroner:** No.
- **CC Regional Flood Center:** This agency integrates with the National Weather service (NWS) and the NWS Observer Network, with TV stations that have their own rain gauge system, and with NDOT when scour measuring at the bridges.
- **FAST:**

- **Henderson PD:** According to Henderson PD, most of the agencies use a version of Form 5. There are two software programs that agencies use either Cross Roads or Vision Tech. Henderson PD uses Vision Tech. Some agencies use hard copies of the Form 5 and write their reports by hand. A meeting of the Traffic Record Coordination Committee (TRCC) is held quarterly. The TRCC is chaired by Dean Reynolds of the NHP and is coordinated by Chuck Abbott of the Nevada Office of Traffic Safety. The next meeting will be held on July 18-19 in Reno, Nevada. Police agencies from across Nevada participate in these meetings. Also in attendance are NDOT, NCATS, DMV, and emergency services, since they run the rural ambulances.
- **LVMPD:** We send our crash data to the state repository.
- **NDOT:**
- **NHP:** NHP shares data with both the Traffic Report Coordinating Committee (TRCC) and with the Southern Nevada Traffic Taskforce. This information is used to locate locations where “directed enforcement” is needed. The Clark County Traffic Enforcement Detail, a combination of law enforcement agencies, is used for directed enforcement.
- **RTC:**

In general, what are your findings when you compare information with other agencies?

- **CC Fire:** Most of our information sharing is in order to determine arrival times of units, any patterns that are developing as far as type of incidents, costs, etc.
- **CC EM:**
- **CC Coroner:**
- **CC Regional Flood Center:** RCFD has the most and best weather and flood flow information.
- **FAST:**
- **Henderson PD:** This police department asked about the capabilities of the cameras that FAST uses, and inquired if they would be useful in detection. Henderson PD also asked about the DMS and whether this system can be used similar to how they are used in CA, providing messages on estimates of how long to major interchanges. This Department wants more traveler information than is currently provided, which may reduce “road rage” incidents and reckless driving incidents. Finally, Henderson PD is looking into Opticom Message Boards which uses a VMS at the intersection to inform motorists about which emergency vehicle is approaching and where to move.
- **LVMPD:** This police department does not routinely compare data with other agencies.
- **NDOT:**
- **NHP:** The Nevada Highway Patrol finds that they have the same problems as other law enforcement agencies, namely, too many incidents and not enough manpower.
- **RTC:**

Incident Management Benefits

How is information (benefits and costs) of your incident management program communicated to decision makers? Rate the effectiveness of each form of communication using 5 for the most effective and 1 for the least effective.

	Fire	EM	Cmr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Personal communication		5						3		5
Electronically (internet, e-mail, etc)								3		5
Print (brochure, newsletter, magazine. Etc.		3						3		3
Other								3		

How is information (benefits and costs) of your incident management program communicated to the public? Rate the effectiveness of each form of communication using 5 for the most effective and 1 for the least effective.

	Fire	EM	Cmr	RFC	FAST	HPD	LVMPD	NDOT	NHP	RTC
Personal communication		5						3		2
Electronically (Television, internet, e-mail, etc)		4						3		3
Print (brochure, newsletter, magazine. Etc.		4						3		3
Public Meetings		3						3		3
Other										

Please indicate any additional information/data that you believe is valuable in accessing the benefits and costs of incident management clearance.

- CC Fire:
- CC EM:

- **CC Coroner:** The Coroner's Office appreciated being included in this process. In order for the Coroner's Office to provide the best possible service to their stakeholders, they need to understand more completely the need for lead time and information about the scene as well as perform needs assessment. Information regarding the best routes to arrive to the scene could greatly reduce the response time.
- **CC Regional Flood Center:** This agency is looking for information on road systems, specifically regarding water over roadways. They indicate that they need "eyes" in the field for flooded roadways. Periodic lists of observations during flood events provide locations of CCTV to RFCD so they can reference locations of rain events to CCTV locations for surveillance and verification.
- **FAST:** A great deal of what FAST does is in the planning stages, will be planned, or is currently under development. FAST is effective in working with NHP where there is such coverage as cameras and signs.
- **Henderson PD:**
- **LVMPD:**
- **NDOT:**
- **NHP:**
- **RTC:**

Additional information

- **CC Fire:** It would help to get a report of traffic conditions and instructions regarding the best arrival route.
- **CC EM:** The Emergency Management team appreciated being included in this process.
- **CC Coroner:**
- **CC Regional Flood Center:**
- **FAST:**
- **Henderson PD:**
- **LVMPD:**
- **NDOT:** NDOT hopes that what comes out of this project are guidelines that will establish how to develop a program in the future. This agency hopes that this report reveals a way to get all agencies involved to determine what needs to happen legislatively and to determine how incident management will be handled in the future.
- **NHP:** The Nevada Highway Police would like to see better interoperability. For example, a statewide radio system would be useful, as would also statewide CAD system.
- **RTC:**

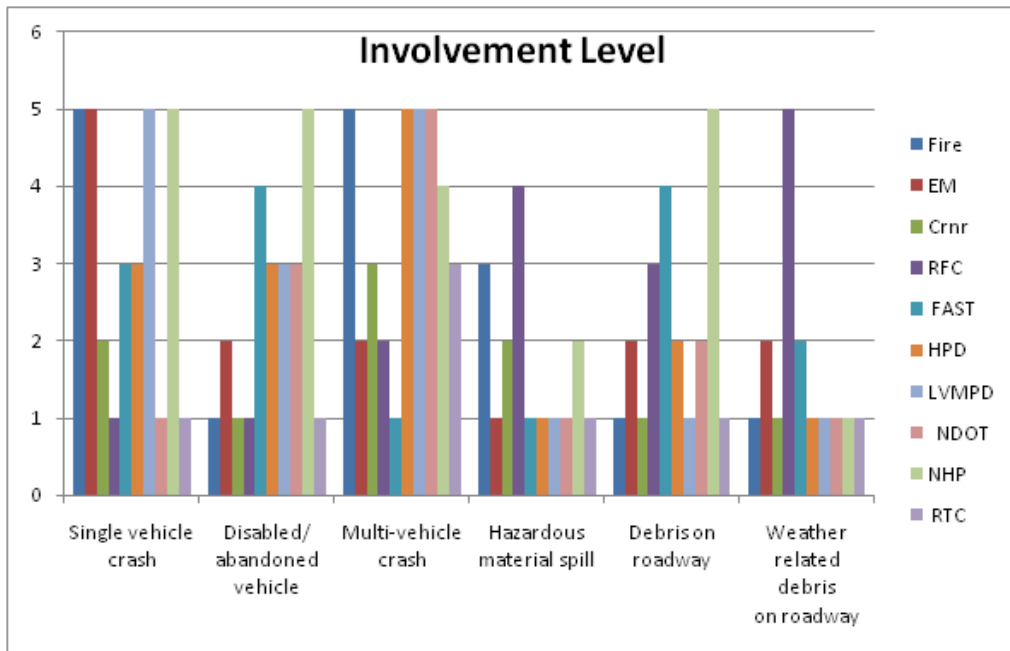


Figure 5.1: The level of involvement of agencies for different types of incidents

5.1.3 Discussions and Suggestions

Incident Definition

When agencies were asked to define incidents, most emergency responders defined them as those events that need their services. Even though the answers seem to be similar, they contain a high degree of inconsistency since different agencies attend incident scenes under various circumstances. In addition, certain non-recurrent events are never reported. However, the answers clearly indicate that FAST, NDOT, and RTC consider any event that affects normal transportation operation as an incident. The definition that each agency gave directly reflects their operational responsibility. FAST, NHP, and RTC are more concerned with the overall “smooth” operation of the traffic system. However, the rest of the agencies are concerned about an incident only when they are involved.

Ultimately, it is very important to realize how agencies operate and understand the mentality of the agency in order to be able to coordinate and enhance communications between them, particularly on-scene. A management unit that is concerned with the overall operation can be developed. This unit has to understand the specific responsibilities of each agency and manage the process as a whole in the sense that this unit is involved beyond the point of informing the proper agency of the incident occurrence.

Level of Involvement of Agencies

As shown in the graph in Figure 5.1, a single vehicle crash, disabled or abandoned vehicles, and multi-vehicle crashes all have high level of involvement from agencies. This indicates that coordination can become an issue in such scenarios. However, those types of incidents that do not have high agency participation must be studied through data, specifically, response rate and clearance times.

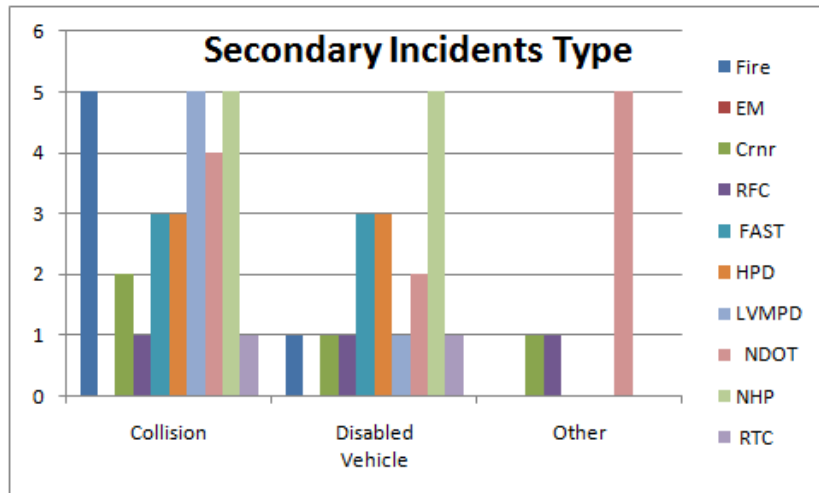


Figure 5.2: The different types of secondary incidents

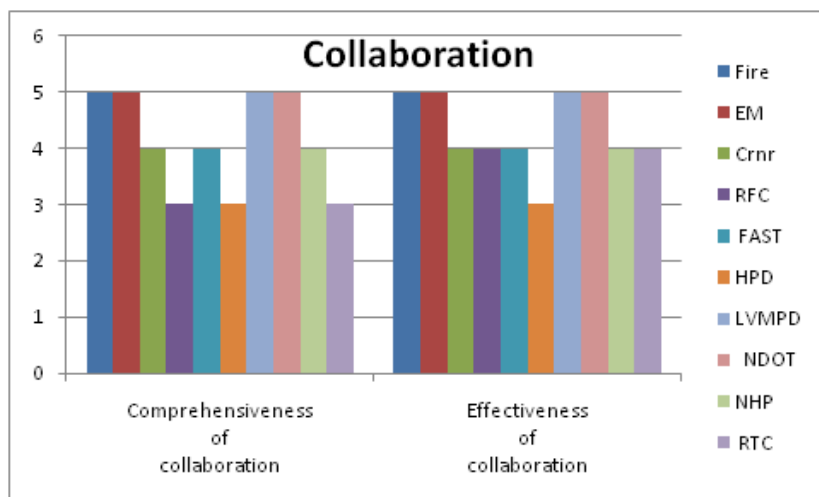


Figure 5.3: Comprehensiveness and effectiveness of the collaboration among agencies

Types of Secondary Incidents

According to most agencies, secondary incidents are normally either in the form of a collision or disabled vehicles. However, it is clear from Figure 5.2 that there is a great deal of inconsistency regarding what type of incident is more common. A proper data analysis must take place in order to accurately determine the different types of secondary incidents.

Collaboration among Agencies

Comprehensiveness as well as effectiveness of collaboration between agencies obtained similar rating, on average. Both criteria averaged approximately, a rating of 4 as depicted in Figure 5.3. However, it is not clear what every agency considered as effective or comprehensive.

Law Awareness

In the graph in Figure 5.4, values have the following indications:

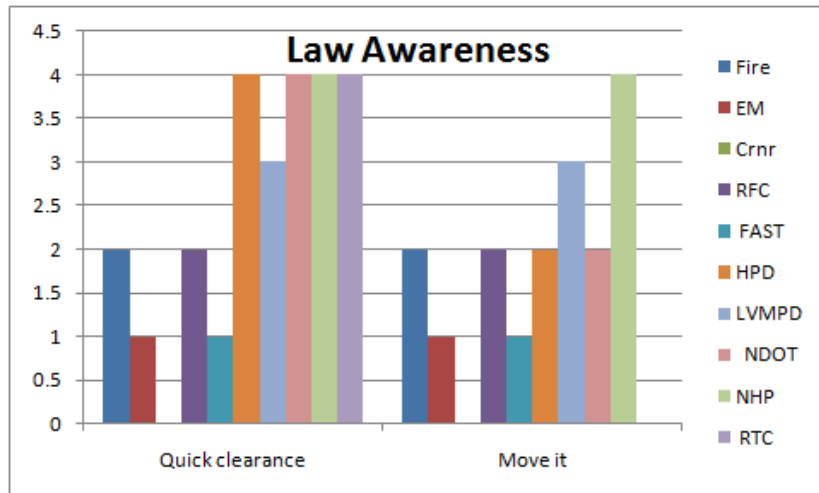


Figure 5.4: Agencies awareness of the “Quick Clearance” and the “Move It” laws

1. Unknown if legislation exists
2. No existing or proposed legislation
3. Bill currently proposed
4. Yes

Figure 5.4 demonstrates the lack of awareness in laws related to traffic incidents. Agencies, especially, law enforcement must be clear on the status of relevant laws since that will provide them with confirmed actions to be executed on the incident scene. Furthermore, miscommunications among agencies are bound to occur due to such confusions. LVMPD have expressed that they do not support such laws since liability and insurance fraud issues can take place. Moreover, most agencies are not aware whether or not a legislation exists that protects incident management responders from liability issues, and some expressed that there is no such legislation.

Intelligent Transportation Systems (ITS)

As presented in the graph in Figure 5.5, the current incident management detection methods rely greatly on highway patrol communication, cellular phones, and traffic cameras. It is important to notice that traffic cameras and highway patrol coverage are mainly restricted on freeways. The arterial incident detection system relies heavily on cellular phones. The automated incident detection technology is not currently used. Call box detection method is not very common in the Las Vegas region.

Among all methods, cellular phones are consistently rated as one of the most used and efficient methods for incident detection, verification, and communication. This confirms the need for the proposed enhanced IM communication and data collection system using Smartphones, as presented in Figure 6.3 in Chapter 6.

Regarding the handling of the incident management process, FAST and NDOT were the only agencies that filled this section properly. At the time of the survey conduction, FAST had traffic cameras, dynamic message signs, and a traffic management center already implemented.

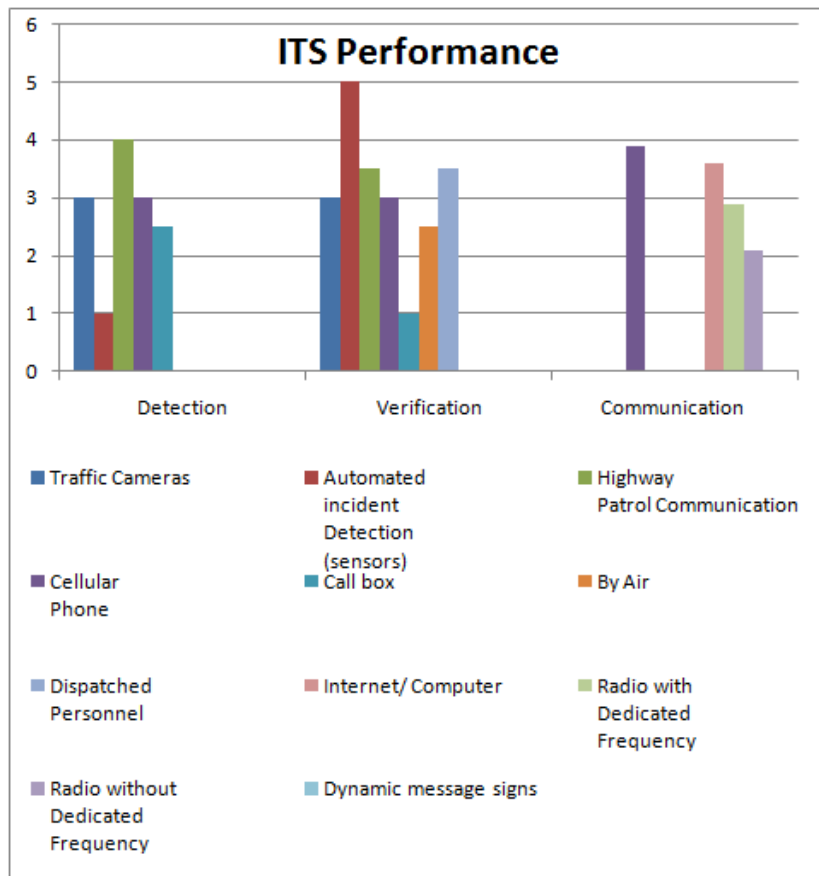


Figure 5.5: ITS performance in detection, verification, and communications, 1 being the worst and 5 the best

Automated incident detection and automated vehicle locators were planned to be implemented. However, there was no discussion on implementing highway advisor radio or dynamic lane designation. NDOT only had the highway advisory radio implemented, but had implementation plans for the rest of the listed technologies.

Equipment

Fire Department, Henderson PD, and LVMPD filled out this part of the survey. Fire has indicated that they have the following equipment available: a heavy duty truck, sweeper, empty box trailer, air cushion recovery vehicle, crane, debris recovery vehicle, and a dump truck. Henderson PD and LVMPD indicated that their equipment mainly consists of a heavy duty truck and a sweeper. NDOT, however, has all equipments available, including an empty tanker truck, an empty box trailer, and an empty live stock trailer.

Incident Management

Route Diversion: None of the agencies claimed that they have an alternate route plan except for RTC. It is crucial to realize the importance of alternate route plans, which can majorly contribute to enhancing response times, and therefore incident clearance times of all responding agencies.

Strategies: FAST, NDOT, and RTC were the only agencies that participated in the strategies question. Notification through dynamic message signs and major equipment for vehicle removal were listed as incident management strategies that are currently used at FAST; however, route diversion is in the planning stages. NDOT has major equipment for vehicle removal. NDOT is in the planning process of implementing route diversion and notification through dynamic message signs. RTC uses multiple strategies such as route diversion, notification through dynamic message signs, agreement with towing companies, and information sharing.

It was noted by some of the agencies that lack of public awareness, coordination between agencies, and media understanding contribute to problematic issues with implementation.

Data

Many data, specifically from phone calls, video recording, and sensor reading that is collected by the various agencies are not kept. FAST and Regional Flood Control (RFC) keep sensor reading data for more than 90 days. Video recordings are kept more than 90 days by RFC, Henderson (HPD), and NHP. Phone calls are kept for more than 90 days by HDP and LVMPD. Please refer to the Results section of the survey for more detailed information about the kind of data each agency collects.

RFC and HPD expressed interest in having better access to FAST traffic cameras. The survey indicates that the data being collected by the agencies is not properly shared among them. Most of these agencies can highly benefit from many of this data. Clearly, a more technologically sound integrated database system as proposed in Chapter 8 is needed for the region in order to enhance the efficiency as well as communications of the system.

Benefit and Cost Information Sharing

Sharing benefit and cost information with decision makers is mostly communicated by NDOT and RTC through personal, electronic, and print communications. Personal and electronics communication was rated as four in effectiveness. However, print type of communications was rated as three. Information sharing with the public is mostly done through personal, electronic, and print communications as well as public meetings. In all cases, effectiveness ranges between 3 and 4 out of 5.

5.2 The “After” Survey

Upon evaluation of the information provided in this questionnaire, it was determined that another survey is necessary to further evaluate the incident management system. This follow-up survey was designed with the following goals in mind:

- **Goal 1:** Extract consistencies and inconsistencies among and within the agencies.
- **Goal 2:** Identify problems involving miscommunication.
- **Goal 3:** Determine policy effectiveness.
- **Goal 4:** Identify what kind of information that agencies collect and how much of it is used so that performance measures can be developed.

There are four sections in this survey:

1. General
2. Policies
3. Communications
4. Data Collection

This survey was designed at the final stages of the project with a very short time left for completion. Therefore, the response rate was not great enough to make any significant statistical conclusions. The survey is included in Appendix A as a reference for the reader.

Part II

Incident Management- Operational

Chapter 6

Incident Management (IM) Modeling and Stages

On a broad level, the goals of an incident management system are to:

- minimize the total delay experienced by travelers,
- maintain or enhance on scene safety for other drivers and responders, and
- use and share resources efficiently.

In this section, the performance of each stage of the incident management will be discussed in terms of the above goals, considering available resources and current practices in the Las Vegas Region.

6.1 Incident Management (IM) Modeling

Traditionally, only 5 incident management stages are recognized; however, in this study, an additional stage is recognized. Incident management has the following recognized stages:

- **Stage 1:** Detection
- **Stage 2:** Verification
- **Stage 3:**
 - Emergency Response
 - Motorist Information
- **Stage 4:**
 - Site Management
 - Traffic Management and Control
- **Stage 5:** Incident Clearance
- **Stage 6:** Congestion Clearance

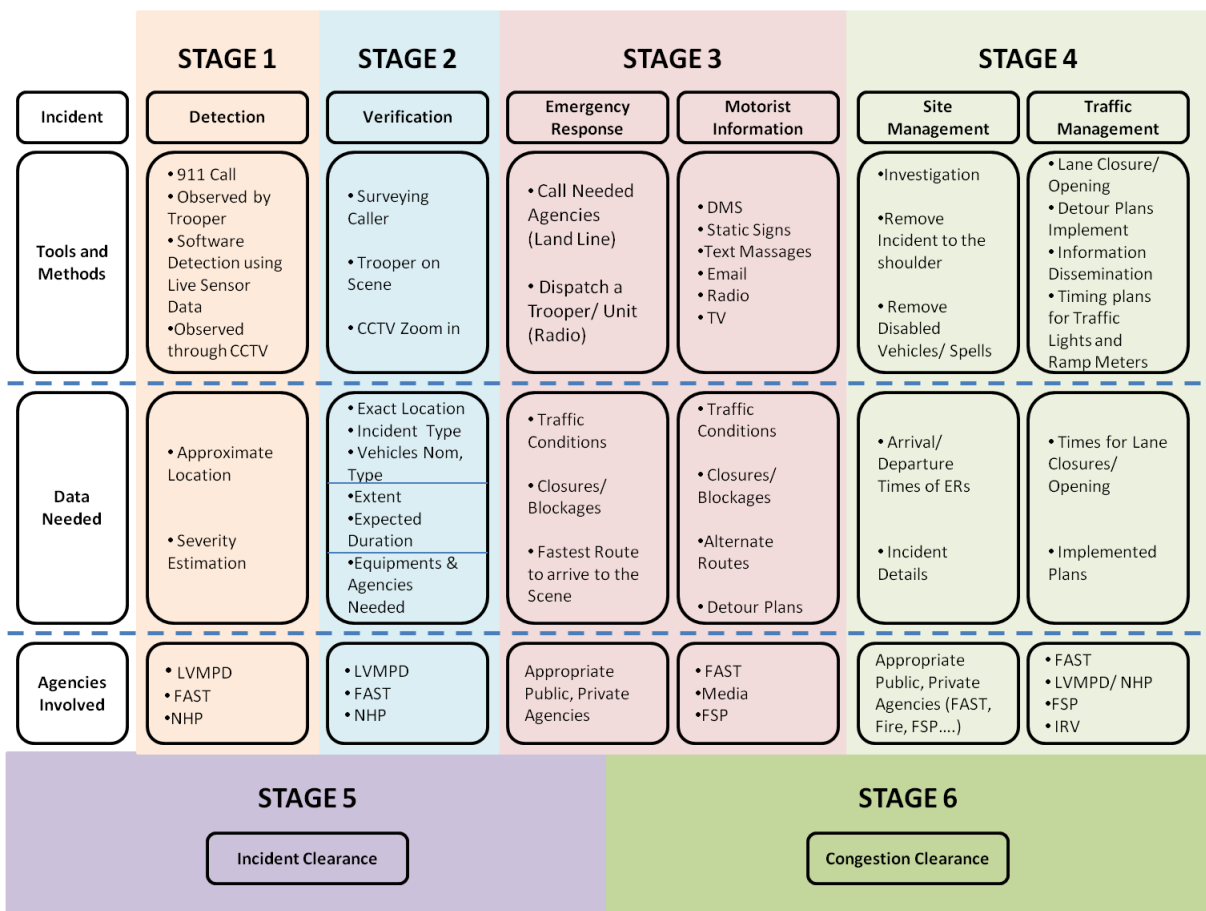


Figure 6.1: The incident management stages hierarchy

6.1.1 Incident Management Hierarchy

The identified stages of the incident management process are a mixture of sequential and parallel events. The hierarchy of the incident management stages is depicted in Figure 6.1.

When an incident occurs, the initial, **Stage 1**, is **detecting** the incident. Incident detection can be accomplished by means of receiving an emergency call (911) or a trooper observing the incident; also, the incident can be detected with the assistance of software that uses live detector data. In the preparation for the next protocol, it is essential to initially determine the approximate location and severity of the incident. In this stage of the incident management process, LVMPD, FAST, and NHP have a vital role: if detection is accomplished by receiving the 911 call, then it will be received by LVMPD call takers who will immediately forward the call to LVMPD, NHP, or Fire dispatch center. The incident could also be observed by either LVMPD trooper, if it is an arterial incident, or NHP trooper, if it is a freeway incident. In either case, to report the incident, the troopers communicate directly with their respective dispatch centers by means of radio. In addition, the incident can be detected by using FAST's CCTVs, which are installed throughout the freeway system. FAST constantly monitors the freeway throughout its hours of operations using live video feed. As a result, it is easy to spot an incident taking place in a location with CCTV coverage. Another method of incident detection is using flow detector data. The existing software can be developed and improved to perform real-time data acquisition and analysis in order to point out the possibility of an incident at a certain location.

The next stage of the incident management, **Stage 2**, is incident **verification**. Obtaining accurate information about the incident becomes important, because whatever information is obtained at this stage forms the basis of the many decisions made later, such as which agencies to dispatch and what equipment is needed at the scene. Such information as the exact location, the incident type, and the number of vehicles involved is needed in order to dispatch the correct agencies. For instance, by determining the location, the dispatcher can make the decision to contact LVMPD for an arterial incident or NHP for a freeway incident. Similarly, by determining the type of the incident, the dispatcher can make the decision on what is needed: Medical, towing services, Fire, the Coroner's office for a fatality, a taxi cab authority if a cab is involved, or HazMat. Obtaining this information also helps in understanding the expected duration of the incident provides information vital for traffic management. Currently, LVMPD, FAST, and NHP are involved in this stage. FAST and NHP work together in order to obtain more details about freeway incidents. If the incident is at a location that is covered by FAST CCTV, then NHP can request that FAST zooms in to have a clearer view of the incident, which will help them determine the impact. In case NHP cannot obtain the needed information using FAST technology, NHP will send a trooper to the scene for verification. If the incident is reported by means of 911 emergency call, usually, the dispatcher surveys the caller in order to obtain as much information as possible about the incident (refer to the verification section for a sample Computer Aided Dispatch questionnaire in Figure 6.5. This holds for LVMPD as well as for NHP dispatch.

As soon as the LVMPD or the NHP dispatcher obtains enough information about the incident, **emergency response** becomes their responsibility; in addition, FAST takes the responsibility of **motorist information dissemination** and traffic control at an early stage, **Stage 3**.

Since events are handled by different agencies, they can be accomplished in parallel. The dispatcher can communicate with troopers of the same agency by means of radio using a dedicated frequency. However, if necessary, the only way to communication with another agency regarding the incident is by means of a landline call. As an initial effort towards Traffic Control, specifically diversion of traffic, FAST can use their Dynamic Message Signs (DMS) to display an informative message about the incident location. Furthermore, if drivers are subscribed, FAST sends out a text message as well as an email informing subscribers about the incident location (refer to the Site and Traffic Management section, Section 6.4.2, to view a sample). At this stage, FAST, NHP, and LVMPD all play a key role in disseminating information to other agencies and to the public. Based on the type of incident and required equipment needed for clearance, multiple public and agencies might be contacted by the dispatcher. For example, in case of severe injury, where ambulance services might be needed, the coroner's office must be contacted in case of a fatality; the NV Taxi Cab Authority must be contacted for investigation when a cab is involved in an incident; or hazardous material (HazMat) clean up services must be contacted when HazMat spills are involved.

Once emergency responders arrive to the scene, **site and traffic management, Stage 4**, begins. Congestion reduction as well as safety of drivers and responders are normally the top priorities of the emergency responders. This is accomplished by safely placing signage in the proper places in order to warn incoming traffic. With the "Move it" law, everyone is required to move the incident to the shoulder whenever this is possible. However, this becomes slightly more complicated when investigation and other procedures are required. At this stage, the on-scene troopers can remain in communication with the dispatcher to convey information back and forth; the dispatcher's responsibility is to track this information, including tracking the operation of the trooper, for instance, arrival and departure times. Multiple agencies can be involved in traffic control. FAST definitely plays a vital role, although currently, only for freeway incidents, because FAST has the ability to monitor traffic through sensors and cameras as well as control traffic through DMSs, ramp-meter timing, and traffic signals timing. At the stage, **Stage 5**, all agencies work together to accomplish quick and safe incident clearance.

Once the incident is cleared, **congestion clearance** begins to take place. At this stage, the roles of most agencies are completed; however, this process can be made faster when traffic control techniques are used. This stage ends when traffic conditions go back to normal or to pre-incident conditions.

6.1.2 Proposed IM Communication Model & ER Coordination in Las Vegas

Considering the existing resources, Figure 6.2 is the proposed communication and relational model for incident management in Las Vegas.

The main idea is for FAST to be the central information source for anything that relates to traffic management. Currently, FAST takes on a vital role in traffic management and information dissemination. However, much more can be accomplished with the available resources and technology advancements. The level of involvement of FAST will depend on the

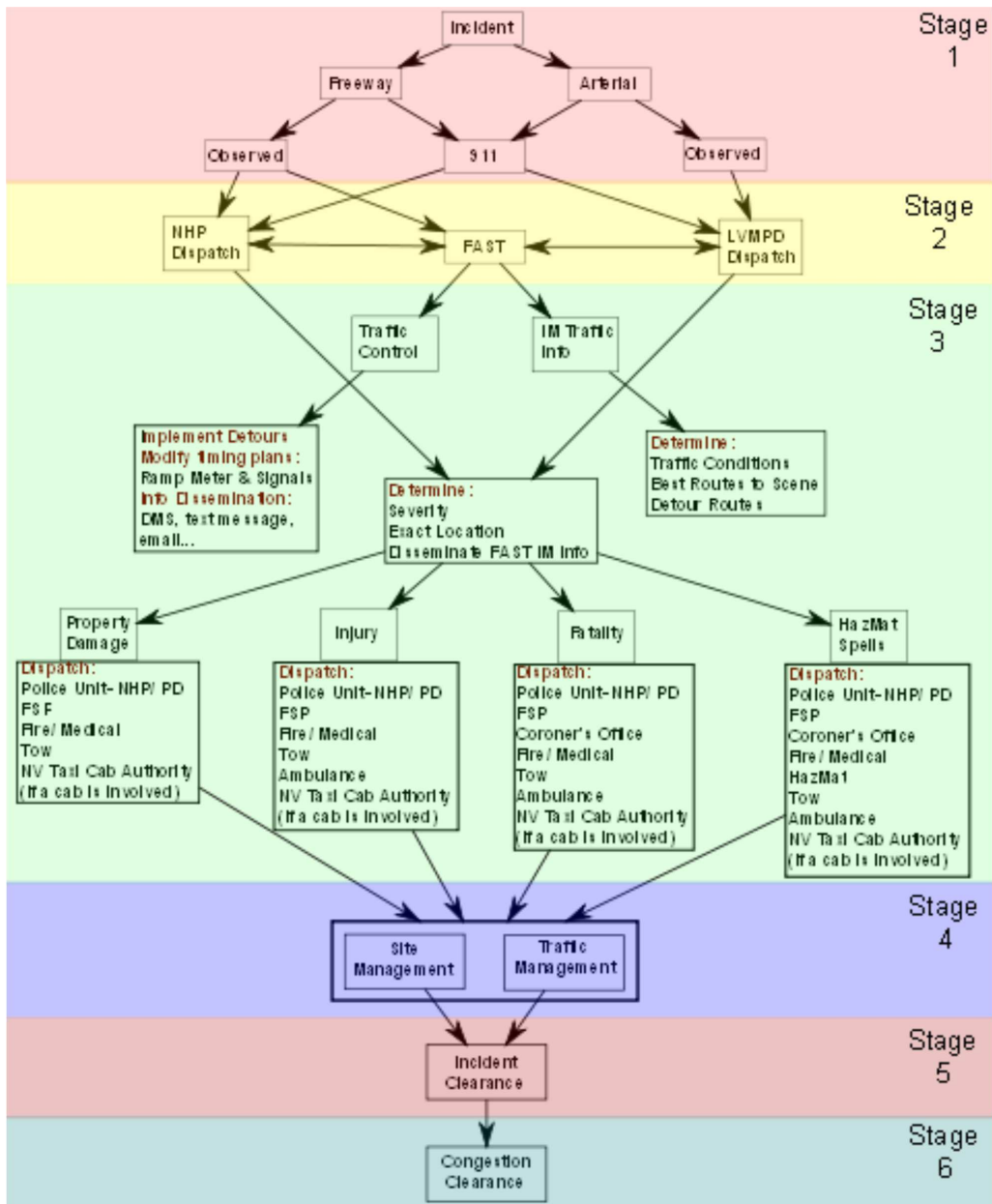


Figure 6.2: Proposed IM communication model

location of the incident and how much observability and controllability FAST has at that location. For simplicity, this section will differentiate between freeway and arterial incidents only, even though, FAST has yet to cover a wider range of freeway. It is proposed that FAST becomes involved at different stages. Assuming a freeway incident occurs, then FAST can be involved in detection and verification stages, as discussed. FAST can communicate this information directly to NHP, since they work side by side. FAST involvement, however, does not stop there. FAST uses their DMSs, email, and text message service to inform the public of the incident location. It is proposed that FAST performs further analysis and posts more information, such as detours or the fastest path, to help guide not only the driver but also the emergency responder. This will be discussed further in the following sections.

Once FAST makes this type of information available to traffic and emergency responders that are involved in the incident management, they will be able to make better decisions, such as what route to take or to avoid in order to enhance arrival rates and reduce incoming traffic. In addition, this information will improve on-scene traffic management performed by emergency responders, for instance, signage placement.

Mainly, given the available data, FAST will perform the appropriate analysis, come up with fastest route and detour routes plans, and make them easily available to all emergency responders as well as drivers. Furthermore, FAST can perform some traffic control by means of ramp-meters and signalized intersections with the help of sensor data.

6.1.3 Proposed Enhanced IM Communication and Data Collection System Using Smartphones

Communications can be enhanced dramatically with the advanced technology available as shown in Figure 1.5. Smartphones are increasing exponentially in popularity. Furthermore, their flexible platforms and Software Development Kits (SDK) make them friendly devices for software developers, with a tremendous amount of applications specifically for transportation. In addition to the SDK, the developer software comes with a library that includes many built-in applications that can be used.

It is proposed that an application be developed for implementation on smartphones that would enhance the IM process by improving communications among emergency responders as well as to the public. Emergency responders and motorists will have the same application installed on their handheld device (smartphone). However, different users will have different access privileges (read/ write) based on their agency.

The application will have different pages for different types of users. For each page, user will be able to input data at two levels:

1. General:
 - (a) Call Receive Time, Dispatch Time, Arrival Time, On-scene Arrival Time, Management Time, Task Finished Time
2. Specific

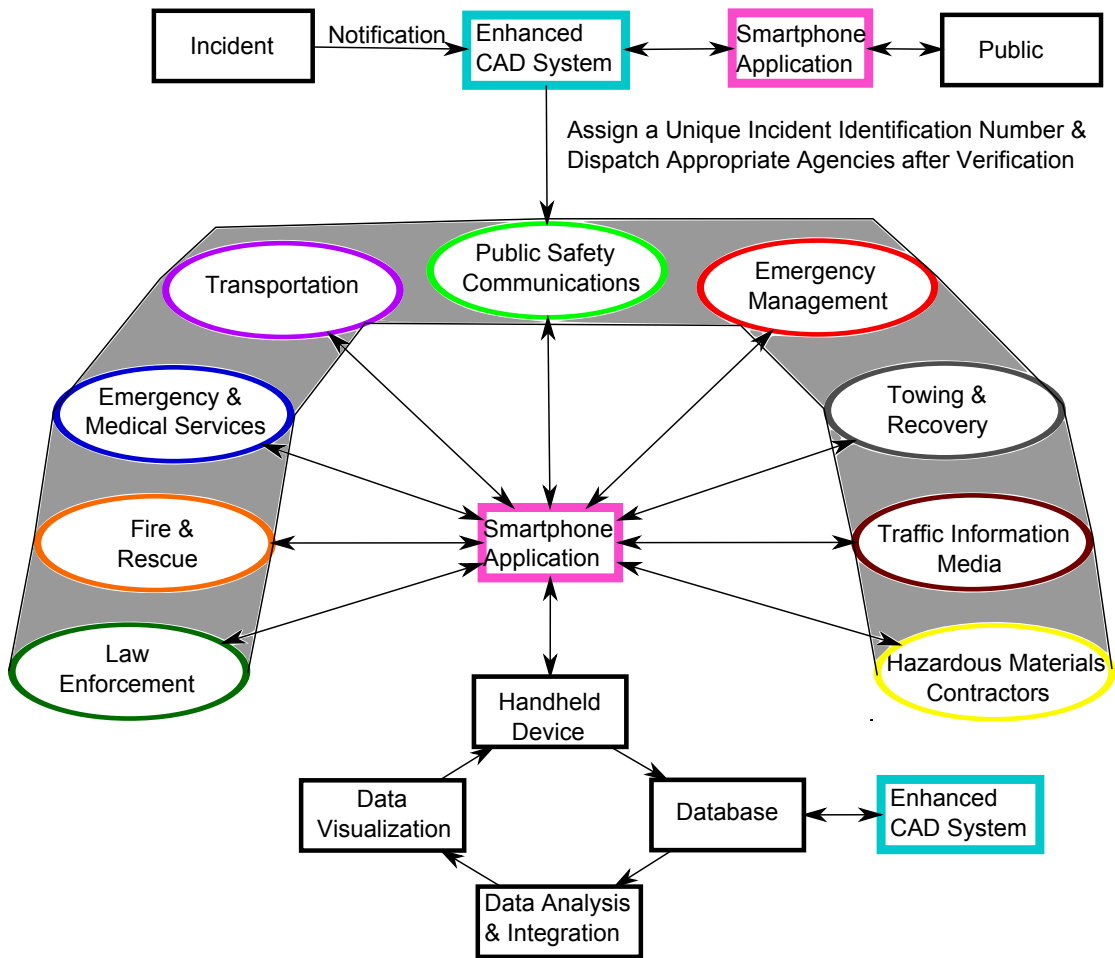


Figure 6.3: Enhanced IM communication and data collection system using smartphones

- (a) **Automatic Information:** Weather Conditions, Longitude and Latitude
- (b) **Law Enforcement:** Unique Incident Identification Number, Timestamp, Exact Location (Longitude and Latitude), Number of Vehicles, Type of Incident
- (c) **Fire & Rescue:** Equipments Needed, Details of Procedures
- (d) **Emergency & Medical Services:** Number of Injuries, Number of Fatalities, Medical Treatment Needed
- (e) **Transportation:** Traffic Conditions, Lanes Closed/ Open, Fastest Route to Scene, Detour Routes, DMS Messages, Ramp Control
- (f) **Public Safety Communications**
- (g) **Emergency Management:** Signage and Placement, Equipment Used
- (h) **Towing & Recovery:** Number of Vehicles to be Towed, Model and Make of Each, Insurance Information, Types of Equipment Deployed
- (i) **Traffic Information Media:** Messages that were Broadcasted, Type of Media
- (j) **Hazardous Material Contractors:** Equipment and Material Used, On-Scene Management Details
- (k) **Public/ Motorists:** Driver Experience, Alternate Routes

Every party can use the unique incident identification number to input details about the incident as soon as they receive them. The application is constantly updated with the most current information. This application also allows the public to be part of the incident management process which can improve incident detection and traffic control. After data is inputted, as shown in Figure 6.3, it will be transmitted wirelessly to an integrated database, and data analysis and integration will be performed. Finally, data formatting and visualization will be conducted and displayed by the handheld device. Therefore, all parties will have access to all the shared data, which will tremendously enhance communications and the decision making process.

6.1.4 Incident Management Queuing Delay Models

Figure 6.4 shows the overall effect of improving incident management on traffic congestion and delay caused by incidents.

Assuming vehicles are at free flow speeds at pre-accident conditions; this indicates that at a certain location, the arrival rate is the same as the departure rate. Therefore, at free flow, vehicles will not accumulate. Graphically, this can be represented as a straight line (assuming constant arrival and departure), the slope of which represents the arrival and departure rates. However, when an incident occurs, arrival rates may stay the same as the pre-accidental conditions; however, the departure rate is abruptly decreased due to blockages the incident may cause. As depicted in Figure 6.4, one can note that at each point of time there are two slopes: 1) an upper slope, which indicates the arrival rate, and 2) a lower slope, indicating the departure rate, that has a lower slope than the arrival line. The differential in arrival and departure rates causes traffic to form a queue. In order to reduce the overall duration of incident clearance, the duration of each stage must be reduced. Moreover, since departure rate becomes greater, the overall queue caused by congestion can be reduced by arriving to the next stage faster. Emergency responders can also improve delay and congestion by improving the processes during each stage, thus producing higher arrival rates, as demonstrated in the second graph in Figure 6.4.

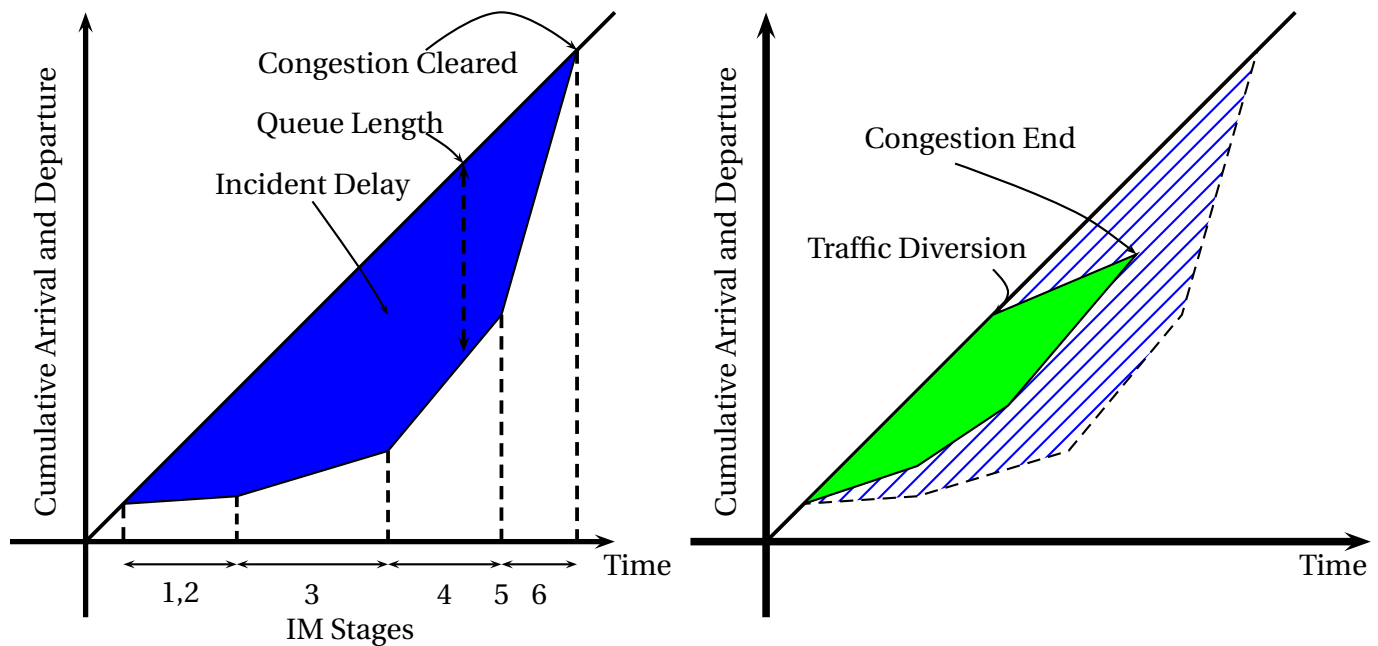


Figure 6.4: Incident management queuing delay model

6.2 Stage 1- Detection

6.2.1 Definition

“Detection is the determination of the occurrence of an incident” (39).

6.2.2 Current Practices

Emergency Call 911

911, is the official emergency number in the United States, is widely used. When an incident occurs, either an observer or the incident victim may place the emergency call to report the incident. Clearly, reporting the incident leads to detection. Many studies have shown that emergency calls are one of the most common methods of incident detection, in particular, those placed using cellular phones (more than 60%) (22).

Observation by a Response Agency

The incident can also be detected by observation of the police trooper or service patrols. This is considered to be one of the most reliable detection methods (37). Studies show that 33% to 50% of incidents are detected by observation of the police or service patrol.

CCTV Detection

FAST detects incidents at locations covered by CCTV cameras installed on the freeway. To report the incident, FAST then can communicate directly with NHP.

In addition to detection methods commonly used in the Las Vegas area, the following are other methods, as stated in the Best Practices In Traffic Incident Management Federal Highway Report 2010 (35).

Motorist Aid Call Boxes

Motorist aid call boxes are roadside communications devices that are permanently mounted. Motorist aid boxes are used mainly by motorists to request assistance or report an incident. Call boxes are typically installed at locations where incidents can contribute significant impacts or else in remote areas with limited communication connectivity. According to a survey conducted in 2007, 10% of the freeway network in the United States was equipped with motorist aid call boxes (35).

Automated Collision Notification Systems (ACNS)

There are a number of commercial Automated Collision Notification Systems (ACNS) available. ACNSs can improve detection of incidents in remote areas. It is based on either the automatic or motorist-initiated activation of an alarm as well as verification of a vehicle's location through the automatic transmission of location data. Global positioning system (GPS) and cellular geo-location techniques are used.

6.2.3 Challenges Limitations of Detection Methods

Identified General Challenges

- **Inconsistent notification of incident responders.** Notification of supporting agencies, such as Transportation, is not as consistent as notification of law enforcement, Fire and Rescue, and EMS agencies. The other issue is that in most cases transportation agencies do not support a 24-hour operation; this affects their role in incident management.
- **Dispatcher overload.** Dispatcher overload occurs when the dispatcher receives multiple calls regarding the same incident. Normally, this causes inefficiency in using the system as well as distracting the dispatcher.
- **Slow detection.** In nonurban areas or remote areas, where there is limited communications and very low volumes, it is very likely that incidents will not be detected. This could threaten safety of the public and individuals involved in the incident, especially if medical care is required. Furthermore, this may increase the probability of occurrence of secondary incidents.

Limitations of Used Detection Methods

- **Emergency Call 911:** Dispatcher overload
- **Observation by a Response Agency:**
- **CCTV Detection:** Currently, arterials are not covered by CCTVs; instead, coverage is only limited to part of the freeway.
- **Motorist Aid Call Boxes:** Slow detection
- **Automated Collision Notification Systems:** Slow detection

6.2.4 Detection Evaluation Criteria

Detection time for most major incidents is found to be approximately 5 to 15 minutes (37). When it comes to optimal detection time, it is inevitable that the lower the better. However, considering the value of time as well as the rapid accumulation of cost due to congestion, an optimal detection time should not exceed 3 minutes. This number, however, highly depends on the location of the incident to be detected.

Evaluation of detection time has always been a challenging task, because incident management data begins once an incident is detected. There are many research studies regarding detection time estimation, and, for the most part, they all rely on traffic sensor data. Fortunately, Las Vegas has the infrastructure and the resources to perform such an evaluation.

6.2.5 Recommendations and Work in Progress

The following is a list of recommendations, suggestions, and work in progress of the issues that were mentioned in the Limitation of Used Methods and the Detection Evaluation earlier in this section.

6.3 Stage 2- Verification

6.3.1 Definition

“Verification is the determination of the type and location of the incident” (39).

6.3.2 Current Practices

911 Caller Survey

If detection is done through a 911 emergency call, then the caller is transferred to the dispatcher of the requested or proper agency. At that point, the dispatcher asks the caller multiple questions in order to obtain more details about the incident, such as the exact location and the severity. This information helps the dispatcher in dispatching the proper units to the scene and in efficiently allocating resources. Figure 6.5 is a sample form from the NHP CAD system that the NHP dispatcher uses. Verification can be improved by enhancing the 911 system to display location information.

NEVADA HIGHWAY PATROL								Page 1		
CAD INCIDENT REPORT										
Location				Cross Street		City				
Incident Type				Call Taker		Dispatcher				
Date	Priority	Primary Unit	Beat	Fire Zone	Area	Map	Source			
Caller Name			Caller Address				Caller Phone			
Dispositions					Weapon	Alm Level	Case Number			
Vehicles		Persons		Sex	DOB	Race	DL	SSN		
Incident Times Received Created Dispatched 1076 1023 Closed Revd-Closed		Unit Times		Dispatched	Enroute	1023	In Service	Disp-1023	1023-In Service	Disp-In Service
Incident Comments										
TIME	EVENT									

Figure 6.5: NHP CAD dispatcher report sample

Table 6.1

Detection Strategy	Challenges	Recommendations	Work in Progress
Emergency Call 911	Dispatcher Overload	<ol style="list-style-type: none"> 1. Enhance the CAD system to detect redundant entries. 2. Enhance the Public Safety Answering Point (PSAP) to detect possible multiple entries by location (if a land line is used) or closest cell phone tower (if a cell phone is used). 	<ol style="list-style-type: none"> 1. Public Agencies are constantly looking for ways to enhance their existing CAD system. 2. TRC-UNLV has been researching methods, algorithms, and system integration possibilities to enhance software elements of the existing IM system
Observation by a Response Agency	The most effective	Dynamic police and service patrol units allocation based on location and time using historical as well as new data. This will increase the possibility that an incident is directly detected by a response agency	<ol style="list-style-type: none"> 1. TRC-UNLV is developing an integrated online database system called IAVID (refer to Section 8) that compiles historical and real time incident as well as traffic data. 2. TRC-UNLV has developed a Bayesian Safety Analyzer model that can assist determining times and locations with high incident probability (refer to Section 11)
CCTV Detection	Limited Coverage	Use dynamic ITS location determination at the design stage of installing additional ITS systems such as CCTV	FAST has been working on installing new CCTVs to cover a wider range of the freeway. Also, FAST is making major plans on covering the arterial system which will allow ITS incident detection.
Motorist Aid Call Boxes	Slow Detection	Call Boxes are not very common in the Las Vegas Area since it is a metropolitan. It will be useful to evaluate and study the possibility of adding call boxes in the region and their impact on incident management detection	
Automated Collision Notification Systems	Slow Detection	Improve Detection Algorithms	TRC-UNLV is working on theoretical modeling and implementation of incident detection using hybrid estimation
Evaluation	Difficult to Obtain Detection Data	Develop an algorithm to extract detection times using traffic detector data form FAST	TRC-UNLV hybrid estimation modeling can be used for this purpose as well.

CCTV Verification

When an incident is detected using FAST's CCTV, the operators can zoom into the incident in order to allow NHP to gather more accurate details about the location and the severity. CCTV cameras also provide limited-access video images for traffic-monitoring purposes. Improvements in picture quality pan, zoom capabilities, and video data transmission rates

have made CCTV a very useful incident verification tool, whereas electronic loop detectors (described in Appendix B) provide detection capabilities.

Field Verification by On-Site Trooper

When the dispatcher is not able to obtain accurate information about the incident from the emergency caller or the CCTV, then an emergency responder unit must be dispatched to the scene for verification. The dispatch unit will communicate details about the incident back to the dispatcher.

Frequent/ Enhanced Roadway Reference Markers

Roadway reference markers can assist incident reporters, such as emergency callers, in reporting the incident location more accurately. Typically, additional directional and route information can be included on the markers. In a recent study conducted by the statewide TIM team in Florida, frequent and enhanced roadway reference markers were beneficial to TIM operations.

6.3.3 Challenges limitations of Verification Methods

Identified General Challenges

Inaccurate incident reports. Normally, motorists are the first to report an incident; however, a great deal of inaccuracy is associated with this detection method in reporting location information and incident conditions, for instance.

Limitations of Currently Used Methods

- **911 Caller Survey:** Inaccurate Incident Reports; inconsistent reports, if multiple callers are involved.
- **CCTV Verification:** Inaccurate Incident Reports.
- **Field Verification by On-Site Trooper:** Inconsistent Notification.
- **Frequent/ Enhanced Roadway Reference Markers:** Inaccurate Incident Reports.

6.3.4 Verification Evaluation Criteria

Reducing the percentage of unnecessary, inadequate, or insufficient response resources dispatched to the incident scene is a good indication of successful verification practices. Furthermore, the percentage of time the dispatcher is able to obtain the correct location information indicates effective roadway reference markers, dispatcher training, and/ or an intelligent software address identification system. This data can be difficult to obtain, however, and only possible by conducting regular surveys as well as data collection by parties involved in a particular incident.

Table 6.2

Verification Strategy	Challenges	Recommendations	Work in Progress
911 Caller Survey	Inaccurate Incident Report	<ol style="list-style-type: none"> 1. Automated caller location identifier (LVMPD dispatch already uses this technology). 2. Enhanced questionnaire design to extract more accurate severity information from caller 	
CCTV Verification	Inaccurate Incident Reports	<ol style="list-style-type: none"> 1. Enhanced CCTV systems with improved resolution, zooming, and maneuvering capabilities. 2. Image processing development for automatic verification 	<ol style="list-style-type: none"> 1. FAST is on top of new ITS technologies. They are constantly looking for ways to enhancing their system. 2. TRC-UNLV has been testing multiple image processing software.
Field Verification by On-Site Trooper	Inconsistent Notification	<ol style="list-style-type: none"> 1. Enhanced communications between trooper and dispatcher in order to obtain incident details through trooper surveying. 2. Using ITS technology such as cameras to take videos and pictures of the incident and transmit to dispatcher. 3. An internet enabled system can be developed, that has ITS capabilities, to be used as means of inner-agency as well as outer-agency communications 	TRC-UNLV is in the process of developing smart phone applications to assist in the incident management unified communications and data collection
Frequent/Enhanced Roadway Reference Markers	Inaccurate Incident Reports	A standardized roadway reference Markers across agencies can enhance their use. Also, a more frequent placement of them.	
Evaluation	Obtaining relevant data can be challenging and may not be available	<ol style="list-style-type: none"> 1. develop a systematic regular routine of surveying emergency responders to obtain all the needed information such as efficiency of resources dispatched after they are done with managing the scene 2. develop methods for automated database storing of data collected from surveys 	TRC-UNLV is looking into survey and database design

6.3.5 Recommendations and Work in Progress

The following is a list of recommendations, suggestions, and work in progress concerning issues that were mentioned in the Limitation of Used Methods and the Detection Evaluation in the previous section.

6.4 Stage 3- Motorist Information & Emergency Response

6.4.1 Definitions

Motorist Information is the “communication of incident related information to motorists who are at the scene of the incident, approaching the scene of the incident, or not yet departed from work, home, or other location.” (35)

Response is the “activation, coordination, and management of appropriate personnel and equipment to clear the incident.” (39)

6.4.2 Current Practices

Motorist Information Dissemination

- **Dynamic Message Signs (DMS).** DMSs are stationary or mobile electronic signs with changeable message postage ability.
- **Text Messaging.** FAST provides a text messaging service, in which a text message is sent to informing subscribers informing them of an incident and its location shortly after its detection. The following is an example of a text message notification:

FRM: Regional Transportation Commission.

MSG: Accident US-95 SB at Russell blocking left lanes. Expect long delays. 01/05/11 10:27am.

- **Email Notification.** FAST provides an emailing service, in which it sends a text message informing subscribers of an incident and its location shortly after its detection.
- **5-1-1 System.** The 5-1-1 system was recently established as the national telephone number for traffic and travel information for specific routes and roadways, including traffic incidents, roadway blockages, lane closures, weather events, transit, and tourism information.
- **Media.** Commercial AM and FM radio and television are used to broadcast traveler information.
- **Traveler Information Websites.** Transportation agencies disseminate traveler information such as real-time traffic congestion, incidents, and updates on construction activities over the website.
- **Standardized DMS message sets/ use protocol.** Using standardized message sets can ensure that appropriate and easily understood DMS messages are displayed.

Response

- **Personnel/equipment resource lists.** A resource lists of personnel or equipment, containing significant resource information can be compiled and maintained by local emergency management agencies. This reduces issues with indirect communication in order to request needed resource.
- **Towing and recovery Vehicle Identification Guide.** The Towing and Recovery Association of America (TRAA) Vehicle Identification Guide is an 8.5 by 11 inch laminated card that can be carried in response vehicles to guarantee that the necessary information, such as the year, make, and model of the vehicle to be towed, is communicated to the tow operators prior to dispatch.
- **Towing and recovery zone one based contracts.** Rotational lists or zone-based licensing are the most common contracting mechanisms for providing towing and recovery services. In rotational lists, a predefined geographic area or zone is assigned a single private towing agency. However, geographic coverage based areas are defined in zone-based contracts. It is expected to enhance response times of towing and recovery.
- **Enhanced computer-aided dispatch.** Enhanced computer-aided dispatch (E-CAD) systems use automatic vehicle location (AVL) technologies to locate and dispatch emergency vehicles closest to the incident scene; this minimizes the response time.
- **Dual/optimized dispatch procedures.** When faced with high volumes, dual dispatch is used, in which response units are dispatched from multiple directions. The first unit that arrives to the scene provides the response; the other units return to their stations.
- **Motorcycle patrols.** Motorcycle patrol units have the advantage of higher maneuverability in areas of high congestion.
- **Equipment staging areas/pre-positioned equipment.** Certain incidents may require large equipment (or equipment that are not easily mobile) to be delivered to the scene. Early request of delivery can improve response time. This may require cooperative agreements regarding the description of stored equipment and their location.

6.4.3 Challenges and Limitations of Motorists Information Dissemination and Response Methods

Identified General Challenges

Motorist Information Dissemination

- Inaccurate traveler information. The lack of a sophisticated surveillance system; miscommunication; and lack of communication among responding agencies, dispatchers, and the media are the main reasons for inaccurate traveler information.

- **Inconsistent dynamic message sign use.** There are two different view on this issue. In the first view, using DMSs for normal message reporting may lead the driver to underestimate the importance of the message being displayed or anticipate what the message should be; as a result, the driver may ignore the message being displayed, even if it concerns an incident. In the second view, having the DMS display a message at all times can potentially cause drivers to habitually look for information in the DMS.

Response

- **Achieving optimum response.** When responding to incidents, two situations should be avoided: under-response and over-response. In the first case, not enough resources are dispatched to comply with the incident clearance needs, potentially consuming more time to clear the incident, increasing congestion, and degrading safety. Over-response, on the other hand, is when more resources than needed are dispatched, which is not efficient in terms of resource allocation.
- **Difficult scene access.** Mainly, roadway design and traffic limit the access to the incident scene. Traffic movement is found to be not effected by flashing lights, specifically amber-colored lights.

Limitations of Used Methods

Motorist Information

- **Dynamic Message Signs (DMS):** Inaccurate Traveler information.
- **Text Messaging:**Inaccurate Traveler information.
- **Email Notification:** Inaccurate Traveler information.
- **5-1-1 System:** Inaccurate Traveler information.
- **Media:** Inaccurate Traveler information.
- **Traveler Information Websites:** Inaccurate Traveler information.
- **Standardized DMS Message Sets/ Use Protocol:** Inconsistent DMS use.

Response

- **Personnel/ Equipment Resource Lists:** Achieving optimum response
- **Towing and Recovery Vehicle Identification Guide:** Achieving optimum response
- **Instant Tow Dispatch Procedures:** Difficult Scene access
- **Towing and Recovery Zone-Based Contracts:** Difficult Scene Access
- **Enhanced Computer-Aided Dispatch:** Difficult Scene Access
- **Dual/Optimized Dispatch Procedures:** Difficult Scene Access
- **Motorcycle Patrols:** Difficult Scene Access
- **Equipment Staging Areas/Pre- positioned equipment:** Difficult Scene Access

6.4.4 Motorist Information and Response Evaluation Criteria

Motorist Information Evaluation

motorist information dissemination must be in real time in order for it to be effective in traffic diversion. Such data such as percentage of motorists that use either method can be helpful in evaluating the strategies used. Normally, this data is not available.

Response

Response evaluation can be assessed by analyzing response time data obtained from incident management agencies. This data is available; however, arrangements must be made for regular collection from agencies and analysis.

6.4.5 Recommendations and Work in Progress

Motorist Information

Please refer to Table 6.3.

Response

Please refer to table 6.4

6.5 Stage 4- Site Management and Traffic Control

6.5.1 Definition

Site management “is the coordination and management of resources and activities at or near the incident scene, including personnel, equipment, and communication links” (35).

Traffic management and control is the use of available data, sensors, and actuators to control the behavior of motorists, as desired, in order to reduce congestion at or near the incident scene.

6.5.2 Current Practices

Incident Command System

The Incident Command System (ICS) is a federally adopted, on-scene command and control protocol that lends consistency to TIM actions, clearly defines command, improves interdisciplinary communication, and more fully utilizes resources (refer to Section 2).

Response Vehicle Parking Plans

Response vehicle parking plans are guidelines and policies that target how responders vehicles should be parked at different stages of the incident management in order to maximize traffic flow, enhance emergency responders’ safety on the incident scene, and improve maneuverability.

Table 6.3

Strategy	Challenges	Recommendations	Work in Progress
Dynamic Message Signs (DMS)	<ol style="list-style-type: none"> 1. Inaccurate Traveler Information 2. Coverage limited to parts of the freeway only 	<ol style="list-style-type: none"> 1. Enhanced communications between FAST and emergency responders specifically NHP and LVMPD. As proposed in the IM communications model in Figure 6.2, FAST can perform analysis using real time traffic data to determine shortest route and alternate route, then communicate the information to motorists, emergency responders, and media partners 2. Enhance communications between Emergency responders and FAST. Emergency responders can communicate to FAST the severity of the incident once verified. This way FAST can estimate the impact of the incident and perform more accurate analysis as mentioned above then inform motorists 	<ol style="list-style-type: none"> 1. FAST has been working on expanding its ITS coverage to other parts of the freeway as well as arterial. 2. TRC-UNLV is looking into using smart phones to develop applications that will assist in enhancing communications between agencies. The idea is integrating the data collected by agencies involved in the response and reporting the data in an easy visual manner that is customized to assist different parties such as motorists, public and private responders, and media
Text Messaging	<ol style="list-style-type: none"> 1. Not Sufficient Traveler Information. 2. Not enough subscribers. 	<ol style="list-style-type: none"> 1. FAST can perform additional real time data analysis using detector data, CCTV, and incident data communicated from responders to come up with possible detour routes, extent of incident, estimated clearance time and include it in the text message. 2. Advertise the service. 	<ol style="list-style-type: none"> 1. FAST has been developing an online visual data system that can be enhanced further and used for this purpose. 2. TRC-UNLV is developing an integrated database. TRC has also been looking into using the capabilities of smartphones to enhance communications among agencies.
Email Notification	<ol style="list-style-type: none"> 1. Inaccurate Traveler Information 2. Not enough subscribers 	<ol style="list-style-type: none"> 1. Enhanced Communications. 2. Advertise the service 	Same as above
5-1-1 System	Inaccurate Traveler Information	Enhanced communications between FAST, Emergency Responders, and the 5-1-1 system managers	TRC-UNLV Proposed Enhanced Communications System using smartphones
Media	Inaccurate Traveler Information	Enhanced Communications System using smartphones	TRC-UNLV Proposed Enhanced Communications System using smartphones
Traveler Information Websites	Inaccurate Traveler Information	Enhanced Communications System using smartphones	TRC-UNLV Proposed Enhanced Communications System using smartphones
Standardized DMS Message Sets/ Use Protocol	Inaccurate DMS use	use flashing light when an emergency occurs	
Evaluation	Data not Collected/ ignored	<ol style="list-style-type: none"> 1. Regularly obtaining data from subscribers of FAST services by surveying. Obtaining Data about the increase of subscription rate. 2. enhanced partnership with the media and website services and data exchange. 3. Conducting regular surveys 	TRC-UNLV enhanced communications and data collection system

High Visibility Safety Apparel/ Vehicle Markings

According to the Emergency Vehicle Visibility and Conspicuity Study, published by the U.S. Fire Administration and the International Fire Service Training Association, several things can be done in order to improve the visibility and conspicuity of emergency vehicles. To mention a few, optimizing interaction with approaching vehicle headlamps can be accomplished through proper placement of retro-reflective and the use of contour markings. The use of fluorescent or high efficiency retro-reflective materials as well as distinctive logos or emblems made with retro-reflective material can be beneficial on the incident scene.

On-scene Emergency Lighting Procedures

It is essential to use emergency lights appropriately at the incident scene, especially at the initial stages of the incident management. Emergency lights warn approaching traffic of the incident and the need to slow down. Furthermore, they serve as guidance to other responder

agencies to help speed up the process. Emergency responders, however, must find the balance in using emergency lights because they can have detrimental effects, such as distracting motorists and causing rubbernecking. It is suggested that the use of emergency lights is reduced as soon as traffic control is accomplished.

Safe, Quick Clearance laws-Move Over

In order to enhance responders safety, “Move Over” laws state that motorists are required to change lanes, if possible, or reduce speed when approaching an incident scene.

Effective Traffic Control through On-site Traffic Management Teams

In most cases, traffic control devices are needed at the scene can be either stationary or mobile. To improve access to the scene and reduce secondary incidents, rapid deployment of control devices can mitigate clearance time through managing traffic.

End-of-queue Advance Warning Systems

End of the queue has a highest probability of secondary incidents due to speed differentials. Therefore, end-of-queue advanced warning systems, such as static, arrow board, or dynamic message signs can be utilized to warn approaching drivers of a downstream traffic queue.

Alternate Route Plans

Traffic demand at the scene can dramatically be reduced if proper alternate route plans, proper signage, and motorists information dissemination is in place.

6.5.3 Challenges Limitations of Site Management and Traffic Control Methods

Identified General Challenges

- **Confusion over authority/roles.**

Disagreements and misunderstandings between emergency responders may delay the process of making decisions, even when the circumstances entail making prompt and even life threatening decisions.

- **Difficult on-scene maneuverability.** Accessing the incident scene often can be a challenging process due to tremendous traffic volume accumulation and roadway design. This also complicates maneuverability at the incident scene, adding limitations to responder vehicles that are parking. This may degrade safety and introduce more delays.

- **Responder Safety.** According to the Bureau of Labor Statistics, since 2003, more than 59 law enforcement, 12 fire and rescue, and 54 highway maintenance personnel have been killed by vehicles along the highway. Responder safety can definitely improve.

- **Secondary incidents.** Secondary incidents are incidents that occur in the range of effect of primary incidents, refer to Section ???. Reducing that effect can reduce the probability of secondary incidents.
- **Excessive delays.** “The 2007 Urban Mobility Report states that motorists in 437 U.S. urban areas incurred \$78.2 billion in congestion costs in 2005, with 52 to 58 percent of the total motorist delay attributed to crashes and vehicle breakdowns” (35). Many aspects can contribute to quantifying these costs, such as lane obstruction leading to capacity reduction time delays, and secondary incidents. One- and two-lane obstructions can lead to 63% and 77% capacity reduction, respectively; an incident on the shoulder of the road may cause up to 17% capacity reduction,

Limitations of Commonly Used Methods

- **Incident Command System/ Unified Command:** Confusion over authority/ roles.
- **Response Vehicle Parking Plans:** Difficult On-Scene Maneuverability.
- **High-Visibility Safety Apparel/Vehicle Markings:** Responder safety
- **On-scene Emergency Lighting Procedures:** Responder safety
- **Safe, Quick Clearance Laws-Move Over:** Responder safety
- **Effective Traffic Control Through On-Site Traffic Management Teams:** Responder Safety and Secondary Incidents
- **End-of-Queue Advance Warning Systems:** Secondary Incident
- **Alternate Route Plans:** Excess Delay

6.5.4 Site Management and Traffic Control Evaluation Criteria

An appropriate performance measurement of on-scene incident management can include 1. the increase or decrease of number of secondary incidents, 2. the number of responders’ injuries, 3. on-scene management duration, and 4. the amount of delay. The appropriate data must be collected from the proper agencies. Furthermore, theoretical analysis and modeling should be conducted in order to come up with appropriate measurements (refer to the Data Analysis as well as the Performance Measures chapters, Chapter 13 and 12).

6.5.5 Recommendations and Work in Progress

6.6 Stage 5- Incident Clearance

6.6.1 Definition

“Clearance of an incident is the safe and timely removal of the incident and termination of the incident conditions”(39).

6.6.2 Current Practices

Abandoned Vehicle Legislation/ policy

This policy serves as a means for quick clearance of minor incidents. It is expected to enhance on-scene safety as well.

Safe, Quick Clearance Laws- Driver Removal

Driver Removal laws, also be referred to as “Fender Bender”, “Move it”, or “Steer It/ Clear It” laws, are in place to speed up the clearance of minor incidents, such as property damage or non-injury incidents.

Service Patrols

Service patrols are considered to be the most effective tool for TIM. The Federal Highway Administration is promoting full functionality (day and night shifts) of service patrols.

Vehicle-Mounted Push Bumpers

Push bumpers are mounted on response vehicles and can be used to quickly clear disabled vehicles. This availability can increase the safety of emergency responders and reduce the probability of secondary incident occurrence.

Incident Investigation Sites

TIM operations can be supported by using investigation sites that provide a safe sanctuary off the roadway so that further investigation and documentation can take place.

Safe, Quick Clearance Laws- Authority Removal

Authority Removal laws provide authorization to a pre-designated set of public agencies generally including state, county, and local law enforcement as well as State Departments of Transportation to remove disabled vehicles, spills, or any roadway blockage.

Quick Clearance Open Roads Policy

Quick clearance agreements are accomplished by setting explicit goals of clearance times for different types of incidents. This encourages responder agencies to cooperate in order to meet these goals.

Non-Cargo Vehicle Fluid Discharge Policy

Spilled vehicle fluids such as crank-case engine oil, diesel fuel, transmission, or hydraulic fluids are not considered to be hazardous wastes. These incidents do not need to be treated as a hazardous material spill, which may extend traffic delays beyond what is necessary.

Fatality Certification/ Removal Policy

Optimization of the decision between thorough investigations and exposure of emergency responders to danger in fatality cases is crucial.

Expedited Crash Investigation

Total station surveying equipment (TSSE) can electronically collect data about the incident scene; for instance, locations of evidentiary items can be measured and recorded by using horizontal distance, horizontal angle, and vertical rise, captured simultaneously. This can speed up the investigation process when compared to traditional methods such as tape based, coordinate, or triangulation methods.

Towing and Recovery Quick Clearance Incentives

Financial incentives for quick clearance and pricing deterrents for slow clearance can tremendously improve performance of first responder agencies.

Major Incident Response Teams

Major incident response teams consist of high ranking individuals from various first responder agencies, such as law enforcement, fire and rescue, and transportation. These teams go through special training and respond to major incidents together. They should be available 24 hours a day, 7 days a week.

6.6.3 Challenges Limitations of Clearance Methods

Identified General Challenges

- **Abandoned Vehicle Hazards** Vehicles can become disabled for multiple reasons, such as mechanical failure, gasoline depletion, or a flat tire. In these cases, drivers tend to leave their vehicles in order to find assistance. However, emergency responders normally tag such vehicles as being abandoned. In most cases, the vehicles are allowed to be abandoned for more than 24 hours; this will most likely decrease safety at the scene.
- **Lengthy minor incident clearance.** Extended clearance times of minor incidents lead to an increase to response personal being exposed to danger, the likelihood of secondary incidents, higher traffic delay, greater fuel consumption, and harmful emissions.
- **Lengthy major incident clearance.** Major incidents normally result in multiple lane blockages, which tremendously degrade the highway capacity and scene safety, as well as increase the likelihood of secondary incidents.
- **Liability Concerns.** Liability costs may be associated with an unnecessary fatality, serious injury, or additional damage to vehicles that are being handled on the scene. Responders should pay attention to the following points:
 - In many instances, the vehicle can be already damaged and unusable.
 - In certain cases, insurance may cover damage costs.
 - Liability costs attributable to extra damage are negligible in comparison to costs that are associated with extra delay and secondary incidents

Limitations of Commonly Used Methods

- **Abandoned Vehicle Legislation/Policy:** Abandoned vehicle hazards
- **Safe, Quick Clearance Laws-Driver Removal:** Lengthy minor incident clearance
- **Service Patrols:**Lengthy minor incident clearance
- **Vehicle-Mounted Push Bumpers:**Lengthy minor incident clearance
- **Incident Investigation Sites:**Lengthy minor incident clearance
- **Safe, Quick Clearance Laws-Authority Removal:**Lengthy minor and major incident clearance. Liability concerns.
- **Quick Clearance/Open Roads Policy:**Lengthy minor and major incident clearance
- **Non-cargo Vehicle Fluid Discharge Policy:**Lengthy minor and major incident clearance
- **Fatality Certification/Removal Policy:**Lengthy minor and major incident clearance
- **Expedited Crash Investigation:** Lengthy minor and major incident clearance
- **Quick Clearance Using Fire Apparatus:** Lengthy minor and major incident clearance
- **Towing and Recovery Quick Clearance Incentives:** Lengthy minor and major incident clearance
- **Major Incident Response Teams:** Lengthy minor and major incident clearance

6.6.4 Clearance Evaluation Criteria

Clearance can be evaluated by measuring various aspects such as clearance times with respect to type of incident, public awareness of laws and policy, the awareness of emergency responders to policies, and the efficiency of task distribution among responders.

6.6.5 Recommendations and Work in Progress

6.7 Stage 6- Congestion Clearance/ Recovery

6.7.1 Definition

Recovery is the time it takes traffic congestion that was caused by an incident to go back to normal conditions (normal in the sense of expected traffic conditions at a certain space and time).

6.7.2 Current Practices

At this stage, traffic agencies can enhance clearance times by applying traffic control methods as mentioned previously.

Table 6.4

Strategy	Challenges	Recommendations	Work in Progress
Personnel/ Equipment Resource Lists	1. Achieving optimum response	Update the list regularly. 2. Integrate the list into the existing CAD system. 3. Develop a software algorithm for automatic resource allocation	
Towing and Recovery Vehicle Identification Guide	Achieving optimum response	1. Enhanced responders training. 2. Enhanced Communications.	TRC UNLV Proposed Enhanced IM Communication and Data Collection System Using Smartphones; refer to the Section: Proposed Enhanced IM Communication and Data Collection System Using Smartphones
Instant Tow Dispatch Procedures	Difficult Scene Access	1. Enhanced Communications between FAST and responders	TRC UNLV Proposed Enhanced IM Communication and Data Collection System Using Smartphones; refer to Section: Proposed Enhanced IM Communication and Data Collection System Using Smartphones
Towing and Recovery Zone-Based Contracts	1. Difficult Scene Access. 2. May not be the most efficient resource allocation	1. Enhanced CAD system 2. Enhanced Communications	TRC UNLV Proposed Enhanced IM Communication and Data Collection System Using Smartphones; refer to Section: Proposed Enhanced IM Communication and Data Collection System Using Smartphones
Enhanced Computer-Aided Dispatch	Difficult Scene Access	Enhanced communications system	TRC UNLV Proposed Enhanced IM Communication and Data Collection System Using Smartphones; refer to Section: Proposed Enhanced IM Communication and Data Collection System Using Smartphones
Dual/Optimized Dispatch Procedures	Difficult Scene Access	Enhanced communications system	TRC UNLV Proposed Enhanced IM Communication and Data Collection System Using Smartphones; refer to Section: Proposed Enhanced IM Communication and Data Collection System Using Smartphones
Motorcycle Patrols	Difficult Scene Access	Enhanced communications system	TRC UNLV Proposed Enhanced IM Communication and Data Collection System Using Smartphones; refer to Section: Proposed Enhanced IM Communication and Data Collection System Using Smartphones
Equipment Staging Areas/Pre-positioned equipment	1. Difficult Scene Access. 2. Inefficient use of resources.	Enhanced communications system	TRC UNLV Proposed Enhanced IM Communication and Data Collection System Using Smartphones; refer to Section: Proposed Enhanced IM Communication and Data Collection System Using Smartphones
Evaluation	No systematic way of data extraction and analysis	Develop data collection and analysis strategies for regular evaluation	1. TRC-UNLV has been collecting incident management data from NHP and LVMPD regularly. 2. TRC UNLV is developing an online integrated database (IAVID); refer to Section 8

Table 6.5

Management & Control Strategy	Challenges	Recommendations	Work in Progress
Incident Command System (ICS)/ Unified Command	Confusion over authority/roles	1. Enhanced Communications 2. More training based on the ICS 3. Development and integration of the ICS in the current CAD system	
Response Vehicle Parking Plans	Difficult On-Scene Maneuverability	1. Planning traffic control strategies that allows responders more On-Scene Maneuverability 2. Enhancing and developing a structured training program that addresses these issues	1. Emergency responders perform regular training 2. Traffic Incident Management (TIM) programs training
High-Visibility Safety Apparel/Vehicle Markings	Responder safety	Enhanced advanced planning and training that considers various road structures, geometry, and traffic conditions	1. Emergency responders perform regular training 2. Traffic Incident Management (TIM) programs training
On-scene Emergency Lighting Procedures	Responder safety	1. Enhanced advanced planning and training that considers various road structures, geometry, time of day, weather conditions, and traffic conditions 2. Human perception and factors studies	TRC-UNLV has done human perception studies on LED displays
Safe, Quick Clearance Laws-Move Over	Responder safety	1. Enhanced training 2. Enhanced public outreach	
Effective Traffic Control through On-Site Traffic Management Teams	Responder Safety and Secondary Incidents	1. Enhanced communications with FAST 2. Enhanced Training	
End-of-Queue Advance Warning Systems	Secondary Incidents	1. Testing various approaches of traffic control and warnings	
Alternate Route Plans	Excess Delay	1. Developing an integrated data collection system that would update notification messages based on the new information agencies input about the incident	TRC- UNLV proposed an Enhanced IM Communication and Data Collection System Using Smartphones; refer to Section: Proposed Enhanced IM Communication and Data Collection System Using Smartphones
Evaluation	1. Determining secondary incidents is a challenging task 2. Responder safety data may not be tracked 3. Data on effectiveness of on-scene traffic management is not easily available 4. On-Scene management time data may not be accurate	1. A unified and strategic data collection plan 2. Data analysis algorithms and methods must be developed 3. A strategic surveying for responders and motorists	1. TRC UNLV is developing an online integrated database (IAVID); refer to Section 8 2. RC-UNLV enhanced communications and data collection system; refer to Section: Proposed Enhanced IM Communication and Data Collection System Using Smartphones 3. TRC-UNLV is looking into survey and database design As proposed in the IM communications model in Figure 6.2

Table 6.6

Verification Strategy	Challenges	Recommendations	Work in Progress
Abandoned Vehicle Legislation/Policy	Abandoned vehicle hazards	<ol style="list-style-type: none"> 1. As an alternative, States can modify existing legislation specific to unattended/abandoned vehicles to reduce the amount of time that motorists are allowed to leave a vehicle in its location 2. expand the definition of "hazard" to include unattended/abandoned vehicles on the roadway shoulder or median 3. Driver education can encourage motorist compliance with laws and/or policies related to abandoned vehicles 	
Safe, Quick Clearance Laws-Driver Removal	Lengthy minor incident clearance	<ol style="list-style-type: none"> 1. develop publicity materials to raise awareness of driver responsibilities under Driver Removal laws. 2. Increase installation of signs at key locations. 	
Service Patrols	Lengthy minor incident clearance		
Vehicle-Mounted Push Bumpers	Lengthy minor incident clearance	<ol style="list-style-type: none"> 1. Promoting use of full-function service patrols on all urban freeways on a 24/7 basis as full emergency response partners with law enforcement, fire and rescue, EMS, and towing responders 2. Promoting public agency cost sharing and public/private partnerships. 3. Integration of service patrol with emergency vehicle response 	NDOT is looking into emergency response Vehicles.
Vehicle-mounted push bumper	Lengthy minor incident clearance		
Incident Investigation Sites	Lengthy minor incident clearance		
Safe, Quick Clearance Laws-Authority Removal	Lengthy minor and major incident clearance. Liability concerns	Concurrent "hold harmless" legislation or language that protects responders from liability resulting from their actions	
Quick Clearance/Open Roads Policy	Lengthy minor and major incident clearance	The effectiveness of quick clearance policies depends upon the perceived attainability of and focus placed on local clearance time goals and the extent of commitment among TIM agencies in pursuing these goals	
Non-cargo Vehicle Fluid Discharge Policy	Lengthy minor and major incident clearance	The effectiveness of non-cargo vehicle fluid discharge mitigation policies can be compromised if there is a lack of awareness among response personnel and/or reluctance to exercise their full authority under this policy	
Fatality Certification/Removal Policy	Lengthy minor and major incident clearance	<ol style="list-style-type: none"> 1. Allowing a designated EMS unit to certify death 2. Vital signs of fatalities can be telemetrically relayed to an off-site coroner for verification, eliminating the need for the coroner to travel to the site. 	
Expedited Crash Investigation	Lengthy minor and major incident clearance	Total station surveying equipment (TSSE)-that electronically measures and records the locations of evidentiary items using horizontal distance, horizontal angle, and vertical rise captured simultaneously	
Quick Clearance Using Fire Apparatus	Lengthy minor and major incident clearance	allowing AFD personnel to use Fire's on-scene fire apparatus to assist in clearing the roadways	
Towing and Recovery Quick Clearance Incentives	Lengthy minor and major incident clearance	explicit equipment, training, and performance requirements for participating towing and recovery companies.	
Major Incident Response Teams	Lengthy minor and major incident clearance	responder safety; safe, quick clearance; and prompt, reliable, interoperable communications	
Evaluation	Data not regularly collected	Collect relevant data regularly and systematically. Develop an automated real time data analysis system.	TRC-UNLV Database system

Part III

Incident Management- Technical

Chapter 7

Incident Management Related Data Analysis and Processing

Table 7.1: Keywords

50F	NHP Code for Fatality
50P	NHP Code for Property Damage
50H	NHP Code for Hit and Run
50I	NHP Code for Injury
401	LVMPD Code for Accident
401B	LVMPD Code for Accident with Injury
UR	Unit Response Time
UA	Unit Arrival Time
ICA	Incident Clearance Time from Unit Arrival
ICC	Incident Clearance Time from Call Time
Jan	January
Feb	February
Mar	March
Apr	April
Jun	June
Jul	July
Aug	August
Sep	September
Oct	October
Nov	November
Dec	December
Ave	Average
St DV	Standard Deviation

7.1 NHP Data Analysis

The Transportation Research Center (TRC) at UNLV obtained freeway incident management data from NHP for a period of time that spans one year, from January 01, 2008 through June

30, 2009. NHP CAD data distinguishes between four types of incidents:

1. Fatality (referred to as 50F by NHP)
2. Property Damage (50P)
3. Hit and Run (50H)
4. Injury (50I)

7.1.1 NHP CAD Data General Analysis

Table 7.2 presents monthly averages of unit response time (UR), unit arrival time (UA), incident clearance time from unit arrival (ICA), and incident clearance time from call time (ICC) for incidents involving fatality (50F). The plot in Figure 7.1 displays the data for each month. On average, clearance of a fatality-related incident takes six hours with a **standard deviation of 0.045** indicating a significant degree of consistency in clearance times. It is noted from the graph in Figure 7.1 that a significant decline in clearance times occurred during May 2009; however, it went back to average during June. Therefore, no conclusions can be drawn regarding the improvement of the management process of fatality incident. In general, data has shown that the average unit arrival time is less than **15 minutes**. However, in some cases the unit arrival time can be **30 minutes** or more. The average unit response ranges between **4 to 9 minutes**, according to compiled data from all types of incidents.

Table 7.2: NHP CAD data analysis- Fatality

Month	UR	UA	ICA	ICC
Jul-08	0:02:08	0:12:16	5:14:23	5:27:10
Aug-08	0:04:20	0:16:36	6:00:44	6:21:40
Sep-08	0:07:20	0:15:30	4:44:45	5:07:35
Oct-08	0:04:09	0:15:54	5:54:27	6:14:31
Nov-08	0:05:07	0:12:15	5:07:42	5:25:04
Dec-08	0:08:41	0:14:19	5:12:59	5:35:59
Jan-09	0:06:35	0:12:56	6:54:55	7:14:25
Feb-09	0:02:26	0:13:58	5:44:12	6:00:35
Mar-09	0:06:38	0:07:49	5:40:16	5:54:43
Apr-09	0:06:40	0:28:11	7:46:28	8:21:19
May-09	0:03:42	0:13:24	3:47:10	4:04:17
Jun-09	0:03:19	0:11:26	5:37:13	5:51:58
			Ave	5:58:16
			ST DV	0.04455

Table 7.3 presents monthly averages of UR, UA, ICA, and ICC for incidents involving property damage (50P). The plot in Figure 7.2 displays the data for each month. On average, incidents that involve property damage take **one hour and 17 minutes** to clear with a great deal of consistency given that the standard deviation is calculated to be **0.001**. No significant improvement can be concluded.

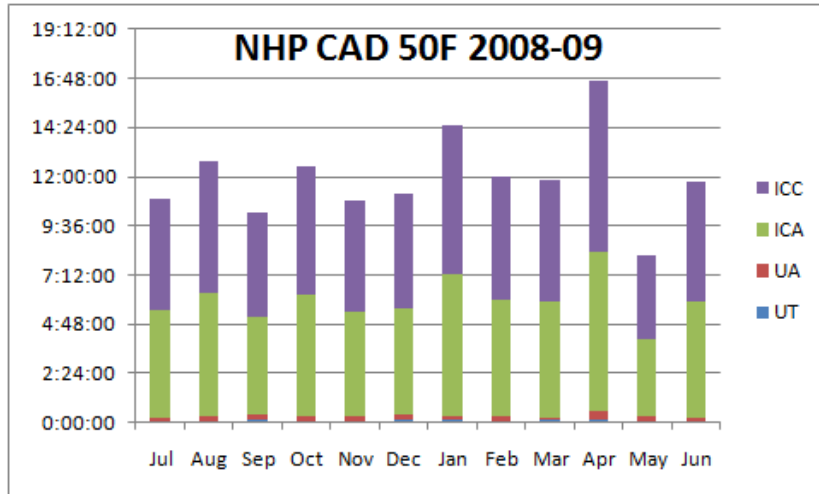


Figure 7.1: NHP CAD data analysis- Fatality

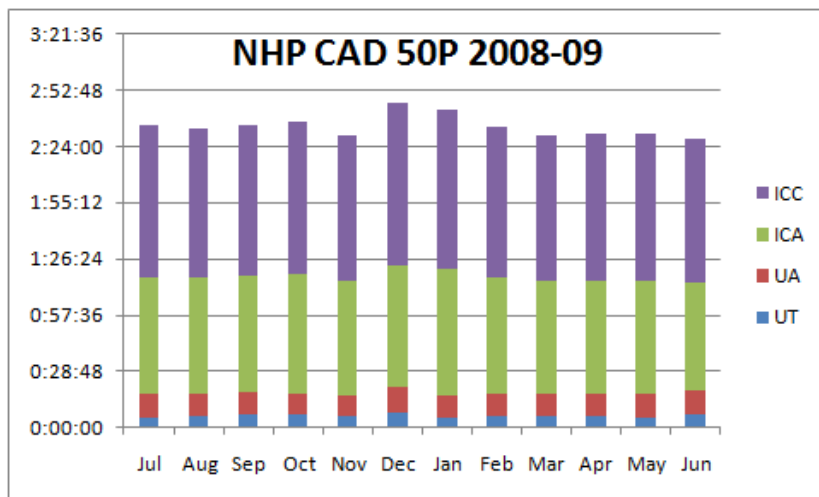


Figure 7.2: NHP CAD data analysis- Property Damage

Table 7.3: NHP CAD data analysis- Property Damage

Month	UR	UA	ICA	ICC
Jul-08	0:05:20	0:11:46	1:00:13	1:17:18
Aug-08	0:06:10	0:10:58	0:59:26	1:16:33
Sep-08	0:06:28	0:11:22	0:59:33	1:17:23
Oct-08	0:06:35	0:11:07	1:00:51	1:18:33
Nov-08	0:06:02	0:10:27	0:58:29	1:14:58
Dec-08	0:07:26	0:12:59	1:02:50	1:23:15
Jan-09	0:05:00	0:11:48	1:04:33	1:21:21
Feb-09	0:06:11	0:11:29	0:59:26	1:17:05
Mar-09	0:05:38	0:11:54	0:57:23	1:14:56
Apr-09	0:05:53	0:11:43	0:57:33	1:15:08
May-09	0:04:58	0:11:55	0:58:33	1:15:26
Jun-09	0:06:33	0:12:08	0:55:12	1:13:54
			Ave	1:17:09
			ST DV	0.001925

More of an oscillatory pattern can be noted in property damage types of incidents as depicted in Figure 7.3 and shown in the data presented in Table 7.4. This type of incident, on average, takes one hour and 13 minutes to clear.

Table 7.4: NHP CAD data analysis- Hit and Run

Month	UR	UA	ICA	ICC
Jul-08	0:07:48	0:10:22	0:48:26	1:06:36
Aug-08	0:08:30	0:12:21	0:48:08	1:08:59
Sep-08	0:06:17	0:13:34	0:59:22	1:19:14
Oct-08	0:08:14	0:12:37	0:51:03	1:11:54
Nov-08	0:13:46	0:14:56	0:50:41	1:19:23
Dec-08	0:07:06	0:13:17	0:53:23	1:13:46
Jan-09	0:07:33	0:11:52	0:58:42	1:18:07
Feb-09	0:07:35	0:10:57	1:03:30	1:22:02
Mar-09	0:06:25	0:12:30	0:50:59	1:09:55
Apr-09	0:08:00	0:11:33	0:52:30	1:12:03
May-09	0:07:24	0:11:22	0:47:57	1:06:42
Jun-09	0:08:45	0:12:07	0:54:26	1:15:19
			Ave	1:13:40
			ST DV	0.003605

Table 7.5 presents monthly average times for incident involving injury. As depicted in Figure 7.4, the average clearance time for these kind of incidents are approximately **two hours**. Note that the difference between clearance times of incidents that involve injury and property damage versus hit and run incidents is 40 minutes, on average.

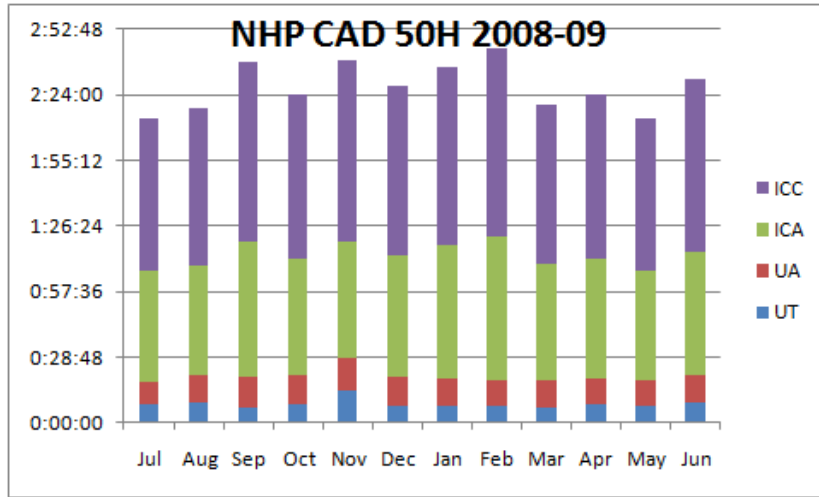


Figure 7.3: NHP CAD data analysis- Hit and Run

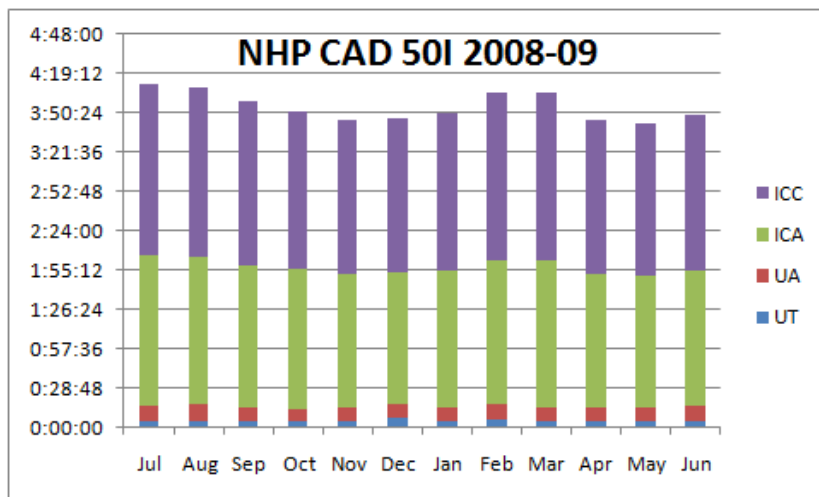


Figure 7.4: NHP CAD data analysis- Injury

Table 7.5: NHP CAD data analysis- Injury

Month	UR	UA	ICA	ICC
Jul-08	0:04:48	0:11:22	1:49:36	2:05:45
Aug-08	0:05:13	0:11:22	1:47:49	2:04:24
Sep-08	0:04:02	0:10:01	1:45:09	0.082787
Oct-08	0:04:13	0:09:33	1:41:56	1:55:43
Nov-08	0:04:29	0:10:34	1:37:39	1:52:42
Dec-08	0:06:36	0:11:07	1:35:40	1:53:22
Jan-09	0:04:13	0:10:12	1:40:23	1:54:48
Feb-09	0:05:36	0:11:17	1:45:35	2:02:27
Mar-09	0:04:01	0:10:54	1:47:38	2:02:33
Apr-09	0:04:06	0:10:49	1:37:26	1:52:21
May-09	0:04:18	0:10:18	1:36:34	1:51:10
Jun-09	0:04:45	0:11:25	1:38:16	1:54:25
			Ave	1:57:24
			ST DV	0.003598

7.1.2 Secondary Incidents Analysis Using NHP Data

Matlab code. The Matlab code for filtering the data is written into four files. File 1 is used to filter the data according to the date and time of the incident's occurrence. The code returns three Excel sheets with the data categorized according to the time of the day, for example, 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.

Results In order to estimate traffic related parameters, the least mean square estimation method was used to obtain the generalized relations. These relations give the estimates of peak, moderate and low traffic volumes from an average traffic volume. From the VISSIM simulation, the rate at which the queue length formed for the peak traffic volume in both directions is 220 and 100 miles/minute. The queue lengths that decreased in both directions by 410 and 350 miles/minute. As the queue gets cleared, the rate of movement of the distraction point is given as 410 miles/minute. Similarly, the rate at which the queue length formed for the moderate traffic volume in both directions is 163 and 77 miles/minute. The queue lengths decreased in both directions are 450 and 325 miles/minute. The rate of movement of the distraction point as the queue gets cleared is 450 miles/minute. The rate at which the queue length formed for low traffic volume in both directions is 65 and 30 miles/min. The queue lengths decreased in both directions by 50 and 220 miles/minute. The rate of movement of the distraction point as the queue gets cleared is given as 450 miles/minute. By applying the above conditions to the Matlab code, the secondary incidents are identified to be **23%** of the total incidents; in addition, the **maximum number of secondary accidents occurred during mid-day.**

7.2 LVMPD Data Analysis

LVMPD CAD data was obtained for the period spanning seven years from 2003 through 2009. The data was first sorted according to two codes: 401 indicating an accident and 401B indi-

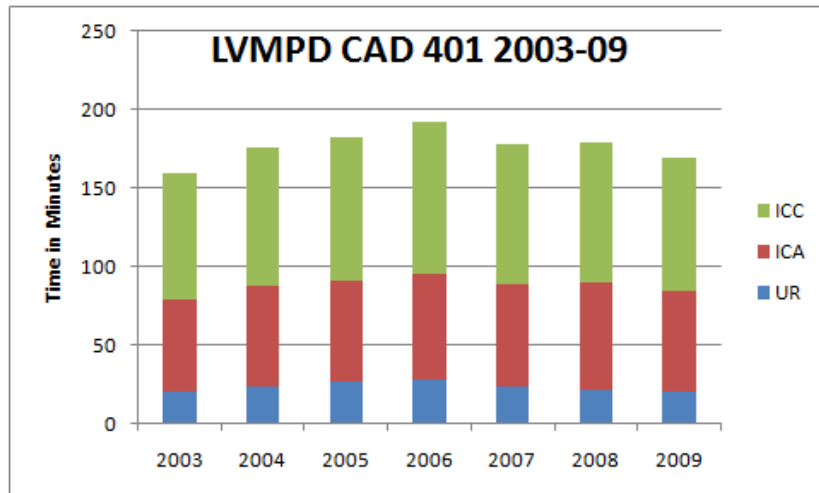


Figure 7.5: LVMPD CAD data analysis- 401

cating an accident with injury. Three types of times were calculated for each code (code 401 and 401B):

- Unit response time (UR) = Unit arrival time - Time the event was reported
- Incident clearance time from the unit arrival (ICA) = Cleared time - Unit arrival time
- Incident clearance time (ICC) = Cleared time - Time the event was reported

The mean of the above three times was plotted per year as shown in Tables 7.6 and 7.7. A general accident (401 type) takes approximately an **hour and 35 minutes** to clear. However, an accident involving injury takes about an **hour and 40 minutes** of clearance time. Note that in general, arterial incidents take longer to clear. Furthermore, it is noted that the average response time is 20 minutes as shown in both Tables 7.6 and 7.7. Plots in Figures 7.5 and 7.6 do not show any sort of improvement in clearance times over the years.

Table 7.6: LVMPD CAD data analysis- 401

Year	UR	ICA	ICC
2003	20.5	59	80
2004	24	64	88
2005	27	63.5	92
2006	27.5	68	97
2007	24	65	89
2008	21	68.5	90
2009	20.5	64	85

Comments

It was claimed that the incident management data obtained from NHP and LVMPD are not accurate in terms of incident clearance times since it is not clear exactly when the units logged out of the incidents.

Table 7.7: LVMPD CAD data analysis- 401B

Year	UR	ICA	ICC
2003	14.5	80	93
2004	12.6	86	102
2005	18	87	104
2006	21	87	108
2007	18	90	109
2008	17	101	118
2009	16	90	104

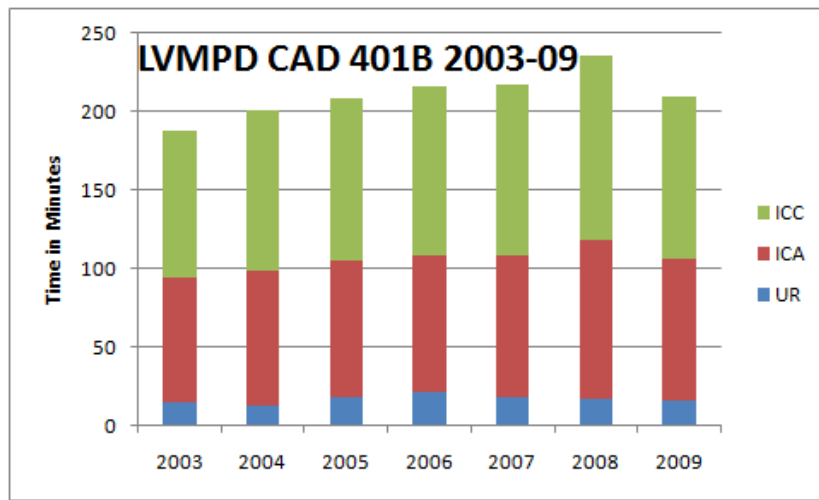


Figure 7.6: LVMPD CAD data analysis- 401B

In order to be able to draw more detailed conclusions on the performance of the incident management system, more thorough data is needed. TRC UNLV has initiated the design and implementation of an integrated database that would serve this purpose (refer to Section 8). However, obtaining data is a challenging task. In order to resolve these issues, system enhancement tools as proposed in Section 6 can be easily integrated with an already integrated database.

Chapter 8

Integrated Analysis and Visually Interactive Database (IAVID) for Transportation Systems

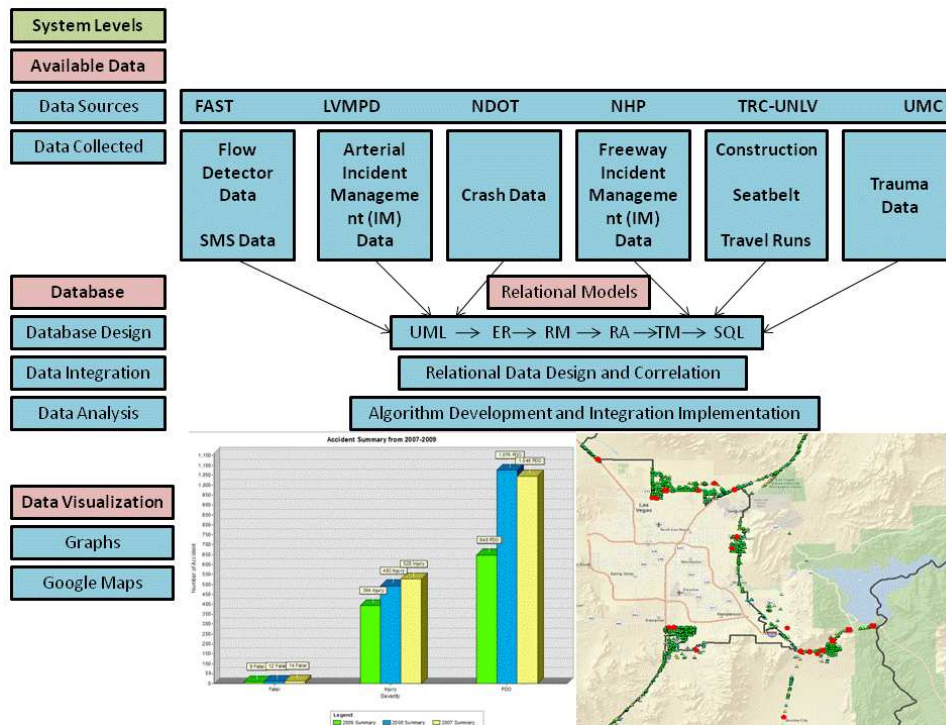


Figure 8.1: Integrated Analysis and Visually Interactive Database (IAVID) for Transportation Systems

8.1 Overview- Why do we need IAVID for our transportation system?

With the enormous increase in traffic demand, which is leading to the expansion of transportation networks and degradation in safety, the transportation system is becoming more

complex. In the hopes of resolving a number of issues, transportation professionals and engineers have demonstrated interest in such aspects of transportation as safety, congestion, incidents, incident management, economic loss, drivers experience, reliability, performance measures, and resource allocation. Ultimately, decision making are all these operational level topics should be studied and analyzed. IAVID is a software system that efficiently performs a comprehensive data integration and analysis. Public and private transportation agencies are making serious efforts and investments in creating an “observable” and “controllable” transportation system infrastructure. Therefore, a tremendous amount of data is being collected from various agencies, and millions of dollars are being spent in hiring data analysts and consultants. The available data is of extremely high resolution, and this requires large databases. Also, this huge amount of data is not very useful in its raw form; therefore, a rigorous and strategic data analysis plan is required to be integrated with the real time data being collected. This integrated system will allow users to make the most out of the data that is being collected in real time by providing real time analysis and visualization. By providing statistically significant timely data and also by correlating causes and effects, a true understanding of the system is gained, which enhances the decision-making process at many levels.

8.2 Data Sources

The following are the data sources from which data is being collected at the TRC:

- FAST- Freeway and Arterial System of Transportation
- LVMPD- Las Vegas Metropolitan Police Department
- NDOT- Nevada Department of Transportation
- NHP- Nevada Highway Patrol
- TRC, UNLV- Transportation Research Center, University of Nevada Las Vegas.
- UMC- University Medical Center

8.3 Data Collected

The following is a list of attribute of the data collected from the various sources:

8.3.1 FAST

- Flow Detector Data
 - TIMESTAMP, PATH, ROADINDEX, ROADWAYID, SEGMENTID, LANE, DEVICEID, VOLUME, VOLUME1, VOLUME2, VOLUME3, VOLUME4, VOLUME5, VOLUME6, SPEED POLLING Period
- SMS Data
 - Date and Time, Location, Lane Blocked

8.3.2 LVMPD

- Arterial Incident Management (IM) Data
 - EVENT NUMBER, CREATE TIME, ARRIVAL PRIMARY UNIT, CLEARED TIME, CODE

8.3.3 NDOT

- Crash Data
 - FID, ACCIDENT-N, ACCIDENT-R, COUNTY-COD, CITY-TOWN, CRASH-DATE, SEVERITY, EVENT-LOCT, CLASSIFY-M, CLASSIFY-L, STREET-PRE, STREET-NAM, STREET-TYP, STREET-SUF, PARSE-SCOR, PARSE-MOD, PARSE-LAST, STREET-PR1, STREET-NA1, STREET-TY1, STREET-SU1, PARSE-SCO1, PARSE-MOD1, PARSE-LAS1, DISTANCE, DIST-TYPE, DIRECTION, ROADWAY-JC, RAW-MILEMA, VEH1-TRAVE, VEH1-TRAV1, RAW-COMMEN, MATCH-SCOR, MATCH-SCO1, NUM-MATCH, RMID, RTE-MEASURE, LOCATION-S, DELTA-FROM, LOCATE-DAT, LOCATE-DA1, LOCATE-SCO, LOCATE-MET, FIPS, GMRotation

8.3.4 NHP

- Freeway Incident Management (IM) Data
 - DATE, LOCATION, PLACE, SRA TYPE (type of accident), TIME, RCVTIME (recieve time), DISPTIME (dispatch time), ENRTTIME, OSTIME, CLEARTIME

8.3.5 TRC-UNLV

- Construction Data
 - DATE, TIME, CLOSURE, DIRECTION, ROADWAY, CLOSURE POINT, END POINT, SCHEDULED WORK, RFC Package, Detour
- Seatbelt Data
 - GENDER, ETHNICITY, AGE, VEHICLE CATEGORY, STATE of REGISTRATION
- Travel Run Data
 - TIME, DATE, LOCATION, SPEED, TRAFFIC LIGHT STATUS, STOPPING TIME AT RED, PROCEEDING TIME AT LIGHT

8.3.6 UMC

- Trauma Data
 - recordno, addr2, plname, pfname, dob, pcity, pcountry, race, sex, pstate, injcity, injdate, ecode, safety, injstate, pre-airway, arrhosp1, arrtime, sbp, sconditn, pre-cpr, dispdate, disptime, ems, seye, sgcs, deptime, spulse, sresp, sts, scenetime, transptime, pretubetho, svrb, injlocate, refairway, ref-arrdat, ref-arrtim, ref-bp, ref-dcdate, ref-dctime, ref-eye, ref-gcs referhosp, hosptrf, ref-pulse, ref-resp, ref-ts, ref-vrb, ed-arrdate, ed-arrtime, arriv-from, chiefcomp, arrivcond, ed-dcdate, ed-dctime, true-los, ed-los, ed-l1activ, ed-l2activ, ed-l3activ, airway, basedef, bloodno, ed-bp, cpr, ed-eye, ed-gcs, ed-mtr, ed-pulse, ed-resp, ed-tsarr, ed-temp, ed-vrb, admservice, ed-disp, assordisp, usraisabd, usraischs, usraisext, usraisfac, usraishn, usrais-iss, usraisst, aiscode, dcode, niss, probofsurv, opcode, opdate, comorcode, hoautopsy, hospdays, icudays dcdate, hosdisserv, hospdisp, nvsup-days, hospchrg, insur

Part IV

Incident Management- Theory and Application

Chapter 9

Formal Language and Automata Theory Modeling of Incident Management

Traffic Incident Management is a multi-jurisdictional process. Complications with communications, compatibility, coordination, institutional responsibilities, and legal issues are inherent in the traffic incident management system. Increased delay in incident clearance due to various conflicts has vital economical, safety, environmental, and social impacts. Therefore, a thorough and rigorous modeling of the system is necessary to better understand its properties and systematically discern issues that might arise. This study proposes the use of formal language and automata theory for modeling and analyzing the traffic incident management process. Incident management is a very practical discipline; however, theoretical modeling and analysis can help in finding inefficiencies in the system and improving it. Formal language and automata theory provides the foundation that has been used successfully in numerous hardware and software developments with applications in digital design, compilers, programming languages, etc. Every agency involved in the incident management process can be modeled as an individual processing unit that interacts with other units. Formal language and automata theory provide us with powerful tools for developing, analyzing, and debugging such models. Creating an incident management model with a systematic structure permits a methodical identification of the system's "bugs". This study demonstrates the development of models of some first response incident management agencies through a case study in the Las Vegas area using formal languages and automata theory. Sequence properties are checked for the developed models.

Glossary for Actions Used in Finite State Process (FSP) Models is presented in Table 9.2(b).

9.1 Introduction

In traffic flow operations, traffic incidents are non-recurring events that often cause delay due to congestion and safety hazards. These incidents account for approximately one third of all delays caused by traffic congestion on U.S. highways and are responsible for nearly 60% of delays triggered by weather, construction, and special events (50). The operating capacity of a typical three-lane freeway segment is reduced by 63% during a one-lane obstruction and by 77% during a two-lane obstruction (11). Incidents, such as a disabled passenger car parked on the shoulder of the roadway, reduce the available capacity by up to 17% (11). The

Table 9.1: Glossary

Action	Translation
alt_route	Alternative route
anthrtow	Another tow
arriveloc	Arrive to location
call_rc	call received
callf	Call fire department
congt_clrd	Congestion cleared (Program 2)
congtn_clrd	Congestion cleared (Figure 9.2)
congtnotclr	Congestion not cleared
driveloc	Drive to location
ernotarrv	Emergency responders have not arrived
ernotreq	Emergency responders are not required
ertaskincmplt	Emergency responders task is not complete
eqptavl	Equipment available
fbusy	Fire department is busy
fmbusy	Fire and Medical are busy
freq	Fire department is required
mbusy	Medical department is busy
mreq	Medical required
noeqpt	No equipment
rdnt_call	Redundant call
tow_nformed	Towing company is informed
townotavl	Towing truck not available
trfcjam	Traffic jam (Figure 9.6(b))
trfjam	Traffic jam (Program 2)

impact of traffic incidents stretches beyond safety degradation and traffic congestion. In addition, Human productivity loss and fuel waste are definite economical outcomes (34) (35). In 2005, congestion costs were estimated to be \$78.2 billion in 437 U.S. urban areas where 52 to 58% of the total motorist delay was due to traffic incidents (11). The benefits of crash reduction or crash avoidance can be significant, as illustrated by an evaluation conducted by the Minnesota Department of Transportation in 2004. This evaluation reported that 68% of the monetary benefits of a traffic incident management program were due to the reduction in crashes.

When an incident occurs, medical, law enforcement, fire, and other public emergency agencies are usually among the first to respond. In addition, private agencies, such as towing companies and hazardous materials contractors, are most likely to be involved (50). On one hand, the existence of specialized entities delivers high quality work in handling tasks at the incident scene. On the other hand, this also raises challenges since each of these agencies has different priorities and views (50).

Moreover, every agency has a separate communication system through which dispatchers communicate information about the incident to their agents. The independence in communication leads to additional delays in the incident clearance process. Carson, et. al. (12) conducted a comprehensive evaluation of an incident response team program for the Washington State Department of Transportation, designed to determine its effectiveness. The

study claims a 20.6 minute reduction in average duration of incidents from 1994 to 1995 resulting in \$20,600 to \$61,800 savings per incident (12). This study concluded that an organized traffic incident management process is necessary that promotes integration and bonding of multi agency operations as well as communications at the incident scene. A well planned incident management system, using both formal and informal processes, improves efficiency and communications between the multi-jurisdictional responses, thus reducing incident clearance times and vehicle delays (34) (35). However, an attempt to create such coordination faces with many obstacles that are inherent in the system, such as uncertainty, sudden events, resource shortage, faulty information, and disruption of infrastructure support (14). In addition to support systems, incident management is currently formulated and implemented conventionally, based on manual methods that rely on personal experiences of the personnel from within the incident management field; which has its shortcomings (17). The current conventional approach does not allow for conflict detection or for alternative incident management scenario evaluation due to time constraints (17). Furthermore, personal experiences are likely limited or else widely varied, they also vary among people's different experiences which may lead to clashes at the incident scene. This often results in further conflicts and difficulties, thus adversely impacting the traffic operations.

This study proposes the use of formal languages and automata theory for modeling and analyzing the traffic incident management process. Formal languages and automata theory modeling allows us to perform rigorous debugging on existing and future incident management systems, covering wide range of possibilities for inefficiencies and problems for which we can find solutions. The modeling approach introduced herein provides the flexibility to evaluate any Incident Management process, depending on the various variables involved for a certain urban region. Through formal methods modeling, customized software tools can be developed for a specific region, significantly enhancing the Incident Management process. In Section 10.2, a literature review on previous work for Incident Management modeling will be discussed. Section 9.3, describes the IM process in the Las Vegas area as well as the Incident Command System (ICS). An overview of the modeling method and approach used are presented in Section 9.4. Section 9.5 presents a demonstration on how formal methods are used to model the IM process by means of a case study. Conclusions are provided in Section 11.8.

9.2 Literature Review

Effective traffic incident management systems consist of three main aspects: multiagency communications and control, decision making, and sharing of limited resources. In order for a model to be successful, these three aspects have to be addressed; otherwise, complications in the incident management system may be overlooked. In this section, some proposed approaches to improve Incident Management processes are discussed.

Sullivan (?) argues key issues in the document, *“Assessing the National Incident Management System;”* in specific communications. In his study, Sullivan evaluates private and public stakeholders that have key roles in the incident management system on a national level and also discusses the administrative or technological challenges. However, Fries (?), examines the effectiveness of specific Incident Management strategies, such as quick clearance laws. He argues that investing in advertisements regarding quick clearance laws are beneficial to

the Incident Management process (?). Skabardonis (?) also examines the effectiveness of specific Incident Management programs. Skabardonis compiled before and after data relating to the implementation of Freeway Service Patrol (FSP) programs. It was found that FSP contributed to the reduction of the number of accidents; however, no significant effect was found on the incidents duration (?). Karlaftis (?) uses regression models and a five-year incident database in order to identify primary incidents' characteristics that increase the likelihood of secondary incidents. Pal (?) analyzes Incident Management data in order to make recommendations to improve the Incident Management.

Konduri, et. al. (28) proposes incident prediction models based on analysis of incident patterns, frequency, and duration and uses them for improving the freeway management system by assessing various IM strategies. Scherer (?) proposes a statistical approach in order to model congestion caused by freeway incidents. Linear regression has shown evident relationships between incident severity and congestion levels that can be used in congestion level prediction (?). Such models would be very useful in incident management systems; however, methods based on static data are not sufficient to comply with the required short term actions necessary in the most effective incident management systems (53). An agent-based approach for monitoring, analyzing, and supporting Incident Management processes by error detection and providing support for such errors is proposed in (16). Temporal Trace Language (TTL) was used as a tool for formal representations of system's properties. The author's approach is adequate; however, the scope of this modeling involves error detection for improving techniques in current incident management support systems that detect contradictory and unreliable information. This approach does not address broader issues in incident management, such as the overall interaction and harmony between the involved agencies, limited and shared resources, or liveness properties of the incident management system as a whole.

Ozbay (?) introduces Rutgers Incident Management System (RIMS) software. RIMS is an evaluation software that is able to compare different incident management technologies and programs as well as strategies (?). Moreover, RIMS introduces a modeling method that can be used to build software for incident management. Mingwei in (17) proposes a real-time Evaluation and Decision Support System (REDSS) for IM that detects traffic incidents, estimates impacts of incidents, formulates guidance scenarios, and monitors and evaluates scenario implementations. REDSS integrates a series of information analysis and processing technologies such as data fusion, expert systems, data warehousing and, data mining (17). However, REDSS has not yet been validated. Chen, in (14), recognizes the constraints on responder's capabilities to analyze coordination problems due to the requirement of rapidness in decision making. Therefore, a life cycle approach is introduced providing a broad and systematic view of activities relating to emergency response management. Rocetti introduces an inter-vehicular communication system design is proposed in (44). This system provides the ability to quickly discover and transmit real time multimedia information from an incident location to the approaching first responders (44). Kim in (24) introduces a conceptual model that explains the efficiency of decision-making of the Critical Incident Management Systems (CIMS) (38).

Researchers have demonstrated numerous attempts in improving the incident management process (17); however, in the history of IM, such attempts have been focused mainly on supporting systems. Such systems are used, in large part, to assist participating agency in assigning tasks and making decisions. These systems may or may not integrate all aspects necessary for a successful incident management modeling as well as implementation of strategies.

A successful IM necessitates a broad and integrated response to incidents (42). The formal languages modeling proposed in this study forms a suitable environment for validation and debugging of supporting expert systems, thus increasing efficiency and accuracy of such systems.

After a great deal of calibration, simulation and modeling based tools are very suitable for evaluation and comparison purposes. For instance, a paper by Sinha develops methodology to predict incidents using such models as Poisson and Negative Binomial.etc. Methodology based on the formal language theory does not compete with these excellent methods. Instead, it provides additional tools to improve the overall system by concentrating on finding “process bugs”.A regular, discrete, simulation-based modeling approach serves a different purpose in Incident Management Modeling than the proposed methods. Hence, since these methods work on different aspects of the incident management process, their results do not address comparable methodologies. In this study, an incident management representation is proposed that provides the ability to account for any desired aspect of the IM process and to integrate the aspects into one systematic model. Moreover, this proposed representation can specify as well as verify properties for the system before implementation. The proposed model provides the ability to validate and verify existing incident management processes, including supporting systems. Most importantly, it provides a method to verify the interaction between such systems as well as between multi-agency processes.

9.3 The Incident Command System (ICS) and Incident Management in the Las Vegas Area

According to the Federal Highway Administration’s *Simplified Guide to the Incident Command System for Transportation Professionals* (FHWA-HOP-06-004, 2006), “The ICS is a systematic tool used for the command, control, and coordination of an emergency response (51)”. The purpose of the ICS is to improve interagency communications through common terminology and operating procedures. However, according to this simplified guide the incident command system (ICS) by the FHWA (51), only 64% of surveyed agencies indicate that an ICS is used on-scene to manage traffic incidents in their jurisdiction. Until recently, Las Vegas has been one of the fastest growing cities in the United States. Consequently, highway capacity investment has not been able to keep pace with the growth in traffic; therefore, major roadways have experienced substantial congestion during off-peak periods as well as peak periods. Users cost per hour for a closure on Highway I-15 was recently estimated at \$240,000 and can go up to \$750,000 during the afternoon peak period. Report produced by Iteris (7) identified the existing institutional relationships, which include operational agreements between various agencies for the Las Vegas area. Furthermore, this report showed the responsibilities of various organizations during an incident management process. Emergency responders in Las Vegas include, but are not limited to, the following agencies: Department of Safety - Nevada Highway Patrol (NHP), Las Vegas Metropolitan Police Department (LVMPD), Regional Transportation Commission of Southern Nevada (RTC), Freeway Arterial Transportation System (FAST), Clark County Office of Emergency Management and Homeland Security, Clark County Fire Department (CCFD), and Coroner’s Office.

In the hopes of resolving any conflicts resulting in an improved communications, enhanced coordination, and an efficient incident management process in the Las Vegas area, a local

traffic incident management (TIM) Coalition has been formed where various emergency responder agencies meet and discuss regional issues involving traffic incidents. The Freeway and Arterial System of Transportation, or FAST, operates the freeway and arterial traffic signal systems. FAST also supports incident management through traffic control (7). According to the Incident Management Strategies Draft Report, incident management is the key motivation for the existence of FAST in Las Vegas. Specifically, FAST provides data and tools to identify incidents and also assists with remote monitoring of the incidents.

Table 9.2: Average Arrival, Management, and Clearance times for incidents that occurred on the I15 and arterials in the Las Vegas area

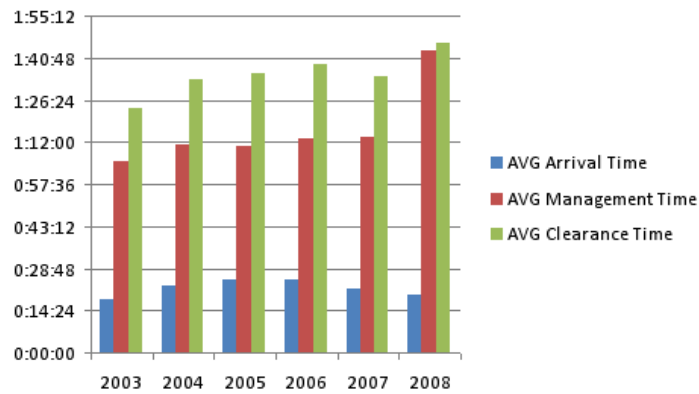
(a) LVMPD data

Year	AVG Arrival Time	AVG Management	AVG Clearance Time
2003	0:18:04	1:05:16	1:23:29
2004	0:22:37	1:11:20	1:33:39
2005	0:25:08	1:10:29	1:35:37
2006	0:25:09	1:13:12	1:38:21
2007	0:21:51	1:13:28	1:34:38
2008	0:19:47	1:43:21	1:46:00

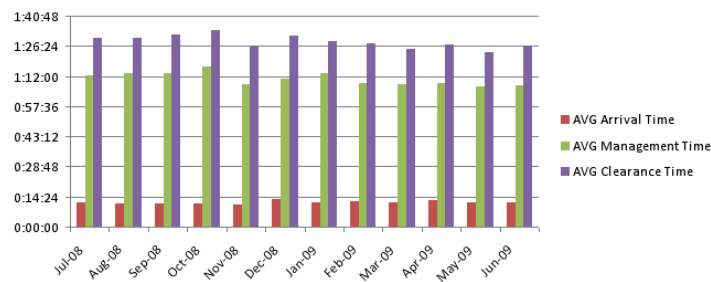
(b) NHP data

Month	AVG Arrival Time	AVG Management	AVG Clearance Time
Jul-08	0:11:30	1:12:04	1:30:01
Aug-08	0:11:10	1:13:22	1:30:27
Sep-08	0:11:06	1:13:18	1:31:35
Oct-08	0:10:53	1:16:39	1:33:47
Nov-08	0:10:43	1:08:20	1:25:59
Dec-08	0:13:21	1:10:58	1:31:33
Jan-09	0:11:22	1:13:12	1:28:49
Feb-09	0:12:12	1:08:40	1:27:29
Mar-09	0:11:42	1:07:50	1:24:54
Apr-09	0:12:38	1:08:42	1:27:07
May-09	0:11:22	1:07:06	1:23:33
Jun-09	0:11:52	1:07:18	1:26:40

Las Vegas has witnessed drastic improvements in the incident management process as a result of FAST efforts in detecting and monitoring incident occurrences and also a result of TIM's efforts to resolve any miscommunication issues among local agencies. However, as found from analyzing crashes obtained from LVMPD (arterial) and NHP (freeway), it was found that the average management and clearance times of incidents need improvement, as presented in Tables 9.2(a) and 9.2(b) and as depicted in Figures 9.1(a) and 9.1(b). Thus, a systematic approach through quantitative modeling is necessary for revealing inefficiencies of the system and understanding its nature.



(a) LVMPD data, incidents occurred on arterials



(b) NHP data, Incidents occurred on the I15

Figure 9.1: Average arrival, management, and clearance times for incidents that occurred in the Las Vegas area

9.4 Model Approach

9.4.1 Formal Languages and Automata Theory Overview

The purpose of formal languages theory is to bring order to complex system anarchy (43). Formal languages are characterized by predefined rules, such as formal notations in mathematics, logic, and computer science (10, 43). A finite automaton is a string processor that assists in defining certain formal languages by accepting or rejecting a sequence of symbols (43). Applications that require pattern recognition techniques have fundamental interest in finite automata (10). A deterministic finite automaton consists of a finite number of states or conditions in which a system can exist. Only one of these states can be an "initial" state. Additionally, such an automaton must contain at least one or more "terminal" or "accepting" states. Transitioning may be performed through two different actions, either switching to another state or remaining in the current state (10). Execution of state transition depends on the current state and the action identified by the symbol.

Using finite automata, a simple example of an incident may be modeled in a pictorial form called a state diagram, as depicted in 9.2. A glossary for Finite State Process (FSP) actions is introduced before the "Introduction" section in this study. State " S_0 " represents a pre-accident situation which might imply traffic is in a free-flow state. The symbol "*accident*"

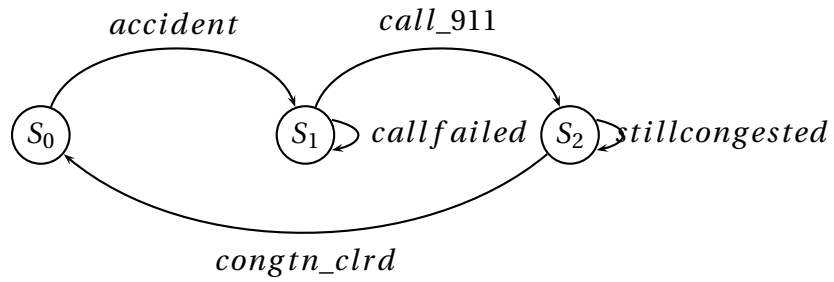


Figure 9.2: A simple state diagram based model for an incident occurrence

represents an occurrence of an incident that causes the system to switch to state “ S_1 ” implying an incident scene. Once the system is in state “ S_1 ” only two transitions are possible represented by the symbols “*call_911*” and “*callfailed*”; the first symbol which causes the system to switch to state “ S_2 ” implying that the incident is in the management process. The second symbol causes the system to remain in the same state, implying that no advancements can be made unless an emergency responder is informed. Once the system reaches the management state, it can switch states when congestion is cleared (“*congtn_clrd*”) and go back to free traffic flow in pre accident conditions (state “ S_0 ”). Otherwise, it remains in the management state “ S_2 ” if congestion is not cleared (“*stillcongested*”).

9.4.2 Modeling and Simulation Software

Labeled Transition System Analyzer (LTSA) v3.0 and Modeling Software is used to construct Finite State Processes (FSP) and to perform property checking on developed models. This is a Java-based open source software. The exact algorithms as well as executions are given in this study under Programs.

Modeling the evolution of an incident scene by using finite automata is methodically appropriate in terms of a sequence of events. Furthermore, many transitioning possibilities can be considered, depending on various conditions, which add flexibility in modeling any Incident Management system. Every Incident Management process, however, is an interaction between multiple processes occurring concurrently. Thus, concurrency is an aspect that must be addressed in the Incident Management model.

Shared actions in Labeled Transition Systems (LTS) Analyzer provide the ability to model concurrent finite state machine processes. They are described textually as finite state processes, and are displayed and analyzed by the LTS analysis tool (30). The LTS analysis tool provides the ability to structure complex systems as sets of simple activities represented as sequential processes using Finite State Processes (FSP) (30). Processes can overlap or run concurrently, reflecting real-world situations as in the Incident Management process.

Finite state processes (FSP) have a predefined language for their description. Actions can be described using the action operator “ \rightarrow ”. For instance, $(x \rightarrow P)$ describes a process that initially engages in the action “ x ” and then behaves as described by process P (30). In order

Program 1 An FSP model for an incident occurrence process

```
PRE_ACCIDENT = (accident->ACCIDENT),
ACCIDENT     = (call_911->CLRNSinPROCESS|callfailed->ACCIDENT),
CLRNSinPROCESS = (congtn_clrld->PRE_ACCIDENT|stillcongested->CLRNSinPROCESS).
```

to model choice, the choice operator “|” is used, for instance $(x \rightarrow P|y \rightarrow Q)$ describes a process that may engage in either action “x”, which leads the system to behave as described by process P, or action “y” leading the system to behave as described by process Q (30). Program 1 demonstrates an FSP process illustrating the incident model described in Figure 9.2.

Program 2 LVMPD model integrating three concurrent processes, Calltaker, Dispatch, and Officer

```
//CALL TAKER PROCESS
CALLTAKER_LVMPD = (call_911->MFP_QUESTION|nocall_911->CALLTAKER_LVMPD),
MFP_QUESTION   = (medical->MED_TRNSFR|fire->FIRE_TRNSFR|police->POLICE_TRNSFR),
MED_TRNSFR     = (med_busy->MED_TRNSFR|trnsfr_med->CALLTAKER_LVMPD),
FIRE_TRNSFR    = (fire_busy->FIRE_TRNSFR|trnsfr_fire->CALLTAKER_LVMPD),
POLICE_TRNSFR  = (police_busy->POLICE_TRNSFR|trnsfr_police->CALLTAKER_LVMPD).

//DISPATCH PROCESS
DISPATCH_LVMPD = (trnsfr_police->INFO_LVMPD|nocall_lvmpd->DISPATCH_LVMPD),
INFO_LVMPD      = (getinfo_lvmpd->RDNCHECK_LVMPD),
RDNCHECK_LVMPD = (rdnlvmpd_call->DISPATCH_LVMPD|newlvmpd_call->ASSN_OFFICER),
ASSN_OFFICER   = (officer_order->OTHER_ER|officer_unavl->ASSN_OFFICER),
OTHER_ER       = (nother_er->DISPATCH_LVMPD|fm_req->CALL_FM|m_req->CALL_M|f_req->CALL_F),
CALL_FM        = (fm_busy->CALL_FM|called_fm->DISPATCH_LVMPD),
CALL_M         = (m_busy->CALL_M|called_m->DISPATCH_LVMPD),
CALL_F         = (f_busy->CALL_F|called_f->DISPATCH_LVMPD).
POLICE_BLOCKEDOPT = (another_route->GOTOscene|no_other_route->STUCK_LVMPD),

//LVMPD OFFICER MISSION PROCESS

OFFICER_LVMPD   = (nofficer_order->OFFICER_LVMPD|officer_order->GOTOscene),
GOTOscene       = (officer_drive->STREET_CON),
STREET_CON      = (trfjam_lvmpd->STREET_CON|blocked_police->POLICE_BLOCKEDOPT|arrive_police->
                  SCENE_LVMPD),
SCENE_LVMPD     = (notneeded_er->TOWorNOT|fm_needed->GET_FM|m_needed->GET_M|f_needed->GET_F),
GET_FM          = (fm_busy->GET_FM|called_fm->TOWorNOT),
GET_M           = (m_busy->GET_M|called_m->TOWorNOT),
GET_F           = (f_busy->GET_F|called_f->TOWorNOT),

TOWorNOT        = (tow_needed->CONTACT_TOW|tow_notneeded->ER_ARRIVAL),
CONTACT_TOW     = (tow_notavl->CONTACT_TOW|tow_informed->ER_ARRIVAL),
ER_ARRIVAL      = (notaller_arrived->ER_ARRIVAL|towarrive_loc->ERTASK_COMPLETION),
                //aller_arrived=towarrive_loc
ERTASK_COMPLETION = (towdone_goback->TRAFFIC_MGT|ertasks_notcmplt->ERTASK_COMPLETION),
                //ertasks_cmplt=towdone_goback
TRAFFIC_MGT     = (congtn_notclrld->TRAFFIC_MGT|congtn_clrld->OFFICER_LVMPD).

//CONCURRENT PROCESS
||LVMPD        = (CALLTAKER_LVMPD || DISPATCH_LVMPD || OFFICER_LVMPD).
```

Concurrency can be modeled by using the parallel operator “||”. For example, $(P||Q)$ represents the concurrent execution of the processes P and Q (30). Parallel processes have the capability to interact via shared actions which are executed at the same time by all partici-

pant processes (30).

Since FSP provides the ability to model parallel processes as well as their interactions, the incident model can be expanded to include an emergency response agency where the occurrence of an incident and the agency's operation are running in parallel and have a shared action "*call_911*". Program 2 illustrates the model of LVMPD based on the corresponding agency in Las Vegas.

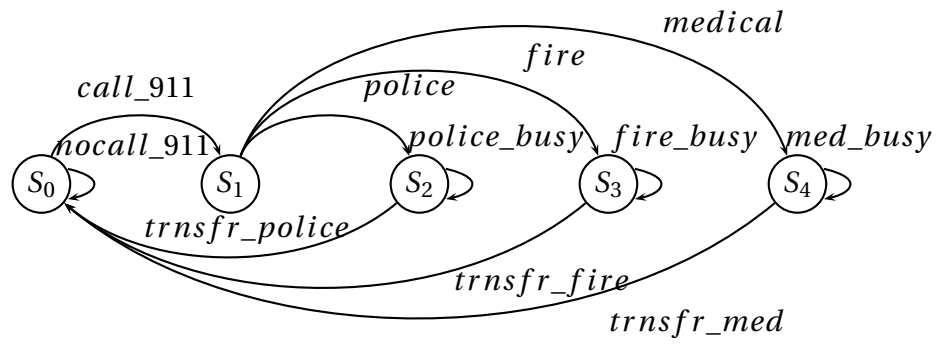


Figure 9.3: A state diagram for the call taker process in the LVMPD model

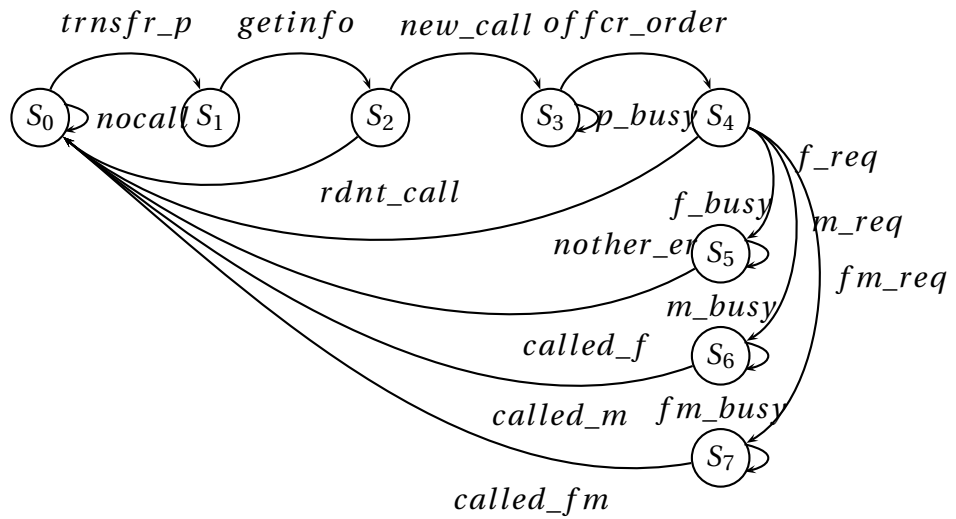


Figure 9.4: A state diagram for the dispatch process in the LVMPD model

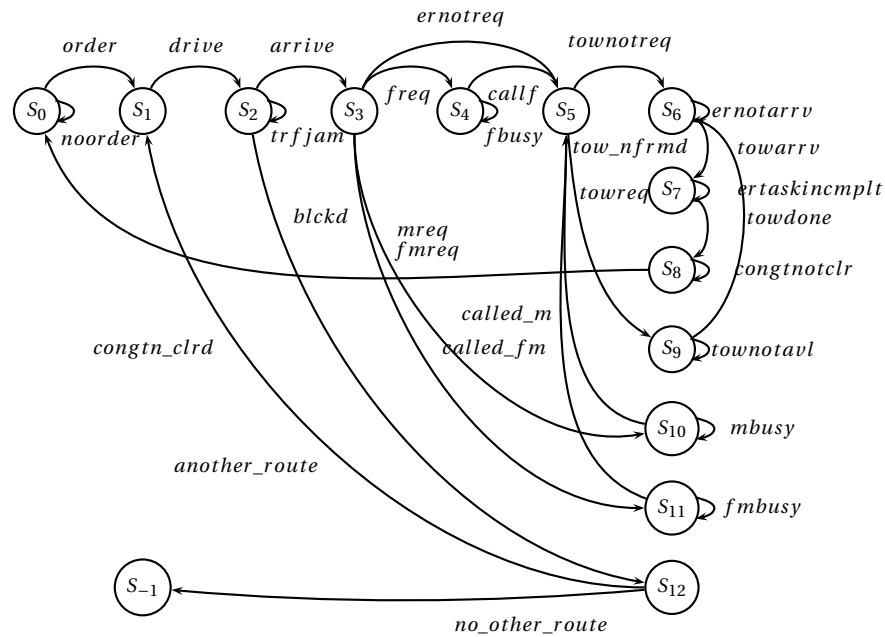


Figure 9.5: A state diagram for the officer process in the LVMPD model

As demonstrated in Program 2, there exist within LVMPD several processes that are executed in parallel and interact through shared actions. LVMPD has three main separate entities that function concurrently: call takers, dispatchers, and officers. When an accident occurs and 911 is dialed (“call911”), a 911-operator (CALLTAKER) from LVMPD will answer the call. The operator has three options for transferring the call: Police, Fire, or Medical. The call will be transferred to the requested agency. Freeway incidents are under NHP’s jurisdiction. Therefore, the call will be transferred to NHP if incident location is freeway. If police is requested, LVMPD dispatch will receive the call, accomplished by the shared action “trnsfr police”, then, LVMPD will acquire information about the incident; verify redundancy of the call; send an officer to the scene (which immediately starts the process of the officer through the shared action “officer order”); contact fire, medical, or both depending on the severity of the incident; and then go back to the initial state, indicating that dispatch is available to accept new calls. As 911-operators and dispatchers are available to receive new calls, an officer is driving to the incident scene and could be faced with various conditions, such as traffic congestion, blocked streets, and faulty information about the actual incident severity. These are all examples of possible scenarios that can be considered in the model. The officer’s task is not accomplished until the system returns to normal conditions. This acknowledgment is achieved by means of the shared action “congtncld” between the LVMPD model and the incident model, as described in Figure 9.2. Figures 9.3, 9.4, and 9.5 demonstrate the state diagram for the LVMPD model in Program 2.

Executing the three processes concurrently produces 520 different states, and the illustration of that becomes challenging to express pictorially. Using FSP and LTSA, properties of states and transitions for the system can be specified and then analyzed. If a system satisfies a given property, then that property is true for every possible execution (30).

There are mainly two types of properties that are of fundamental interest: safety and liveness. Informally, a safety property guarantees that “nothing bad happens”, whereas a liveness property guarantees that “something good eventually happens”. Using temporal logic, a canonical safety property can be expressed as $\Box p$, whereas a liveness property is of the form $\Diamond p$ (31). Formally, p is a safety formula if and only if (iff) any sequence p' violating p , contains a prefix $p'[0..k]$ all of whose infinite extensions violate p (31). p is a liveness formula iff any arbitrary finite sequence s_0, \dots, s_k can be extended to an infinite sequence satisfying p (31).

In the LTS analyzer software, liveness property is checked by using the progress property, of which liveness is a subclass. A progress property is violated if a terminal set of states are found that do not contain any of the progress set actions. In other words, if the officer depicted in Figure 9.5 reaches a state that does not provide a transition back to the desired state for instance, the action “no other route” is chosen - then the system is in state “ - 1,” which does not provide an action for recovery or for reaching “cngstn clrd” action; at that point, the system is not alive or progress property is not satisfied for “cngstn clrd”. The safety property is verified by specifying a set of actions that the system must satisfy at all times. This specification is executed concurrently with the system’s model for analysis. A case study is presented in Section 9.5, using an existing IM model and analyzed using LTS tools.

9.5 Case Study

In a meeting held by the local traffic incident management (TIM) team, where representatives from various emergency responder agencies had gathered in order to discuss regional issues involving traffic incidents, a certain incident (a rollover) that occurred in Las Vegas was the center of discussion. In the rollover, towing services were needed. Therefore, a private towing company was contacted with some information about what kind of equipment was needed and the location of the rollover. However, the tow truck arrived 30 minutes late. Upon arriving, the wrong vehicle was towed. At that point, it was discovered that different equipment was required to tow the vehicle of interest. After that, the officer and the tow company discussed whose responsibility it was to clean-up the scene. This process delayed the scene clearance by two hours. Clearly, such complications are a result of decisions that are made in real time. A systematic way to discover and solve possible disruptions does not exist, leading to inefficiencies inherent in the present system.

In order to model the Incident Management process in the rollover case, the incident and LVMPD models presented in Programs 1 and 2 are used. A model describing the tow company operation is presented in Program 3 takes into consideration the issues discussed relevant to this specific case.

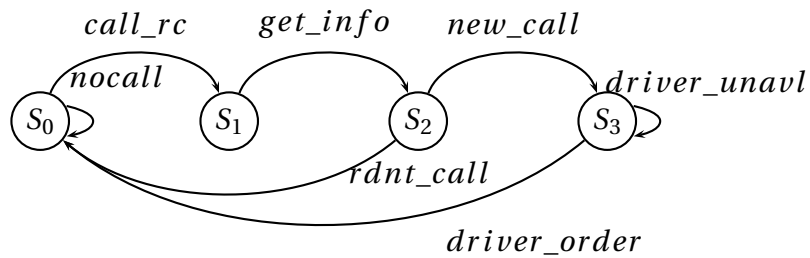
The towing company has two concurrent processes: 1) dispatching which receives calls and information from customers; and 2) delivering (‘driver’) the proper equipment to the scene. State diagrams for the towing company model are depicted in Figures 9.6(a) and 9.6(b).

Program 3 Tow company model integrating two concurrent processes Dispatch and Driver

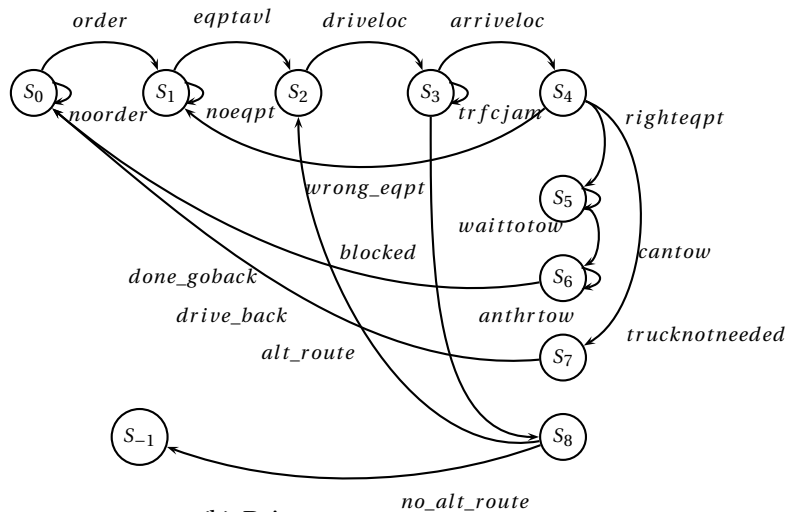
```
//DISPATCH PROCESS
DISPATCH_TOW      = (tow_informed->INFO|nocall->DISPATCH_TOW),
INFO               = (get_info->RDN_CHECK),
RDN_CHECK          = (rdn_call->DISPATCH_TOW|new_call->GIVE_ORDER),
GIVE_ORDER         = (driver_order->DISPATCH_TOW|driver_unavl->GIVE_ORDER).

//TOW MISSION PROCESS
DRIVER_TOW        = (no_order->DRIVER_TOW|driver_order->GET_EQPT),
GET_EQPT          = (eqpt_unavl->GET_EQPT|eqpt_avl->READYtoDRIVE),
READYtoDRIVE     = (drive_loc->TRAFFIC_SITUATION),
TRAFFIC_SITUATION = (traffic_jam->TRAFFIC_SITUATION|blocked->BLOCKED_OPT|towarrive_loc->EVAL_LOC),
BLOCKED_OPT      = (alt_route->READYtoDRIVE|no_alt_route->STUCK),
EVAL_LOC         = (wrong_eqpt->GET_EQPT|truck_notneeded->RESOURCE_WASTE|right_eqpt->WAITtoTOW),
RESOURCE_WASTE   = (drive_back->DRIVER_TOW),
WAITtoTOW       = (waittotow->WAITtoTOW|cantow->CANTOW),
CANTOW           = (another_tow->CANTOW|towdone_goback->DRIVER_TOW).

//CONCURRENT PROCESS
||TOW_COMPANY     = (DISPATCH_TOW || DRIVER_TOW).
```



(a) Dispatch process



(b) Driver process

Figure 9.6: State diagrams for the tow company model

The state diagram representation of the towing company, which includes the two processes "Dispatching" and "Delivering," becomes too complicated to represent pictorially. After the models of the incident scene, LVMPD, and Towing Company are obtained, they are executed in parallel by the process described by the FSP in Program 4.

Program 4 IM process as a concurrent execution of three processes tow company, LVMPD, and Incident scene

```
||ER_MNGMNT = (TOW_COMPANY || LVMPD ||PRE_ACCIDENT)
```

Safety and liveness properties for the system are verified. Safety property is verified by the process illustrated in Program 5, which indicates that at every state, the system is not going into a situation where the process is blocked. The results of the safety analysis execution for the complete Incident Management model and the towing company model are depicted in the simulation results in Program 6.

Program 5 Safety property specification

```
property ACCIDENT_RESOLVED =(accident->call_911->congtn_clrd->ACCIDENT_RESOLVED).
```

```
||ER_MNGMNT = (TOW_COMPANY || LVMPD ||PRE_ACCIDENT| | ACCIDENT_RESOLVED).
```

Program 6 System verification for safety property

```
Trace to property violation in LVMPD.OFFICER_LVMPD:
```

```
accident  
call_911  
police  
trnsfr_police  
getinfo_lvmpd  
newlvmpd_call  
officer_order  
officer_drive  
blocked_police  
no_other_route
```

```
Trace to property violation in DRIVER_TOW:
```

```
call_rc  
get_info  
new_call  
driver_order  
eqpt_avl  
drive_loc  
blocked  
no_alt_route
```

Program 6 implies that there exists a trace where the system does not comply with the safety requirement. Thus, the system is not safe and requires improvement in the specified trace. In this case study, the system is not safe since the officer can reach a blocked state that prevents the arrival to the incident scene. Other safety checks may be specified for the Incident Management system or the individual agencies.

Liveness property is specified by the process illustrated in Program 7 which provides that the system will eventually reach a certain “acceptable” state; the desired action in this case would be congestion clearance “cngstn clrd.” The analysis results of the liveness check program execution is demonstrated in Program 8.

Program 7 Liveness property specification

```
progress LVMPD_MISSION_ACCOMPLISHED = cngtn_clrd
```

Program 8 System verification for liveness property

```
Progress Check...
-- States: 14 Transitions: 107 Memory used: 4022K
Finding trace to cycle...
Finding trace in cycle...
Progress violation: LVMPD_MISSION_ACCOMPLISHED
TOW_MISSION_ACCOMPLISHED
Trace to terminal set of states:
accident
call_911
police
trnsfr_police
getinfo_lvmpd
newlvmpd_call
officer_order
officer_drive
blocked_police
no_other_route
Cycle in terminal set:
nocall
Actions in terminal set:
no_order, nocall, nocall_911, nocall_lvmpd,
  notaller_arrived, stillcongested
Progress Check in: 62ms
```

Formal Methods modeling allows for two types of property checking safety and liveness. After the models were created, the LTSA software was used in order to perform properties checking. Programs 5 and 7 show the exact command lines for checking safety and liveness, respectively. Program 6 and 8 show the results after the execution of the safety and liveness commands. The execution of the safety checking is demonstrated in Program 6, where it lists the accepted strings by the given automata model. However, it reaches the state “no_alt_route.” This clearly indicates that, at some point in time, the process could enter an undesired state. Similarly, when liveness checking was executed, the software entered the “stillcongested” state, indicating that complete clearance is not accomplished. Obtaining these results depends greatly on the user-defined model.

The liveness check indicates that the system will not reach the desired state if it reaches one of the listed terminal states. The analysis in Program 8 recognizes the set of terminal states where progress property is violated. It also provides the trace to terminal states. Therefore, the system is not “alive” and requires improvement in the indicated actions. Even though the issues in the rollover incident were taken into consideration in modeling the IM system, analysis of the model has identified a trace that leads to the action “no other route.” This action is also recognized to be a member of the terminal set whose members avert the system’s

progression.

Ultimately, every Incident Management process should be live, implying it will always eventually reach a desired terminal state where the incident is cleared. Ideally, every Incident Management process should be perfectly safe, signifying that the system is always safe. Safety can take various forms, according to which specifications are executed. For instance, a certain Incident Management system may be considered safe if delay does not exceed a certain amount or if only certain routes are allowed.

9.6 Conclusions

This study demonstrated incident management modeling using formal languages and automata theory. Formal languages methodology provides the ability to perform rigorous debugging and analysis through which robustness of the Incident Management system can be achieved upon implementation. This approach allows analysis to be conducted of processes concurrently executed processes that have specifications for liveness and safety properties specifications. The purpose of this approach is to model the traffic management processes in various coordinating agencies and then to find out if undesirable situations, such as "semaphores locking" exist. This method offers flexibility in modeling various Incident Management systems that account for many possible existing scenarios. Formal modeling can lead to the development of customized systems resulting in a more successful Incident Management process. The approach studied in this study can be expanded to include a wider range of resources for every process within the agencies as well as to model additional agencies that might be involved in the Incident Management process. In addition, this model can be enhanced to include real-time information within the states representing traffic conditions or other continuous, random activities. Finally, real-time data and statistics can be incorporated to support predictions and estimations.

Using formal methods, modeling provides practical and accessible techniques that aid evaluating designs for concurrent software. The incident management process is composed of a combination of sequential and concurrent events that are performed by multiple agencies. Therefore, it is inevitable that incident management software must feature high level of concurrency in its design. Formal methods are found to be very suitable and natural for incident management modeling, from which incident management software can be developed. Using formal methods modeling and its associated features, such as concurrency and property checking, can provide flexible and appropriate tools for software design, leading to enhancement in communications, response, and management. From a practical point of view, formal methods modeling as well as associated software are used in order to ensure that the incident management process is well defined. The user - and in this case, the user can be any of the responder agencies, the Department of Transportation, or any party that has an active role in managing incidents - takes an active role in determining the structure of the model and defining the desired safety and liveness properties.

Formal methods based approach is particularly useful for complex systems where high levels of hierarchy and concurrency are required. Complex models can be built based on modular structure. The software allows modular interaction through event sharing. This method is also useful when quantification of qualitative procedures is needed. For instance, the various Incident Management systems across the nation are evaluated based on the Incident Command. However, the Incident Command system stands as a document that is described qualitatively. This introduces challenges in achieving a common means of evaluation as well as a common structure among the different IM systems.

Chapter 10

Secondary Congestion and Incidents

Incidents on urban freeways usually have a major impact on the normal operation of traffic, causing congestion and delays. What distinguishes incident related congestion from regular congestion is the speed differential. Incident related congestions lead to high differential speeds; this means that the vehicles change speeds abruptly, resulting in settings that are more prone to further incidents. With queues propagating rapidly, the probability of the occurrence of secondary incidents increases in the direction of the incident as well as in the opposing direction. Secondary incidents are of major concern, particularly for the incident management operations of the emergency responders. Emergency responders must adequately evaluate the operational implications of primary incidents for proper resource allocation and prevention of undesired expected or unexpected events. Only a few studies have been carried out to study secondary incidents. However, such studies have defined secondary incidents by means of progression curves that represent static, temporal, and spatial boundaries for the incident related congestion. Static progression is the least accurate for defining secondary incidents. In this study, progression curve models were studied and enhanced to cover the full range of operational effects of primary incidents. A case study in the Seattle, Washington region was used for a thorough study of freeway incidents as well as the progression curves of the associated operational impacts. In addition, simulations from I-15 in Las Vegas were conducted to demonstrate a number of possible scenarios.

10.1 Introduction

Incidents are nonrecurring events caused by crashes, debris dissipation, disabled vehicles, special events, and severe weather conditions, for example, in every case, safety is degraded and the free flow of traffic is disrupted (50) (18). Freeway incidents fall under two categories: independent and dependent (55). The causes of independent incidents are not related to an occurrence of an earlier incident. Dependent incidents usually are composed of a primary and a secondary incident or else a primary and multiple secondary incidents occurring in the same and for the opposite directions near the same time and in close proximity (55). Incidents can cause the capacity of a facility to be reduced by up to 17 percent when zero lanes are obstructed (shoulder only), 63 percent when one lane is obstructed, and up to 77 percent when two lanes are obstructed for a three-lane freeway (11). Incidents and congestion in one direction lead to a certain level of distraction to the traffic in the opposing direction, also

referred to as “rubbernecking” effect, which may reduce capacity by 50 percent (18) (27) (15) (23). Overheating engines, caused by incident related congestion, account for 60 percent of all freeway congestion (49). Consequently, incidents have serious implications due to the resulting traffic congestion they cause approximately 33 to 60 percent of all delays and cost U.S. motorists billions of dollars every year (34) (11).

What distinguishes incident-related congestion from regular congestion is the speed differential. Incident-related congestions lead to high differential speeds; in such cases, vehicles change speeds abruptly, resulting in settings that are more prone to incidents. With queues propagating rapidly, the probability of the occurrence of secondary incidents increases in both, the direction of the incident and the opposing direction. Secondary incidents are of major concern, particularly for the incident management operations of emergency responders. Emergency responders must adequately evaluate the operational implications of primary incidents for proper resource allocation, mitigating clearance times, and prevention of undesired expected or unexpected events.

Secondary incidents are partially or fully related to the occurrence of an earlier event (41). They are a significant source of freeway incidents composing approximately 20 percent of all nonrecurring events (34) (54). Therefore, it is vital to be able to identify secondary incidents for research, management operations at the incident scene, and development of incident prediction tools for Intelligent Transportation Systems (ITS).

Only a few studies have been carried out to study secondary incidents. However, such studies have defined secondary incidents through progression curves that represent static, temporal, and spatial boundaries for incident related congestion. Localized static or dynamic thresholds limited in time and space result in erroneous data for secondary incident identification. Furthermore, previous studies have only considered congestion in the same direction of the primary incident. However, rubbernecking is responsible for 16 percent of all distraction related incidents (15).

Localizing thresholds does not cover all events that are possibly secondary, and that leads to erroneous statistics that are often used in studies, investigations, and incident management processes. In order to minimize secondary incidents, a standard measure for identifying them must be developed by taking into consideration various factors, such as volumes, capacity, and speed, and the dynamic movement of the queue propagation even after the clearance of the incident. Furthermore, congestion that forms in the opposite direction, the “rubbernecking” phenomenon, near the incident must be studied as well. In this section, a dynamic progression curve that is unique to every event and its parameters, such as severity of incident, traffic volume, and clearance times, is proposed.

This section presents a study of the dynamic effects of freeway incidents through a case study in the Seattle, Washington region as well as multiple VISSIM models simulating interstate Highway I-15 conditions in the Las Vegas area. In Section 10.2, a literature review of the studies that have been conducted on incident related congestion and secondary events is presented. A case study from the Seattle area is discussed in section 10.3. Simulations are presented in section 10.4, then, results and discussion are in section 10.5. The last section contains the conclusions.

10.2 Literature Review

Several studies have been conducted on incident related congestions on freeways. In (27), it was shown that the capacity of the freeway was decreased after lane obstruction at the location of a crash. This study also considered the effect of incidents on the traffic going in the opposite direction. It was found that the rubbernecking effect reduces the traffic flow by up to 50 percent (27). The rubbernecking effect was also investigated in (49); 10 percent of considered accidents have shown significant impact on traffic flow in both directions (49). This study pointed out the problem; however, it did not propose any standard measure that can be pursued in future studies. The findings show that the common time and distance thresholds that are normally used in investigating secondary incidents need to be revised and reformulated.

The interdependency between the duration of primary incidents and the occurrence of secondary incidents was explored in (23). It was found that the longer the duration of primary incidents, the higher the probability that secondary incidents occurred; this then can increase the duration of primary incidents (23). This finding highlights the importance of studying secondary incidents. Furthermore, in (23), static thresholds were used to define secondary incidents. According to this study, secondary incidents are those that take place in the same roadway segment as the primary incident, averaging one mile from the incident scene and occurring during the incident duration if no lanes are blocked; if lanes are blocked, the duration increases by 15 minutes. Obviously, the queue length due to incidents may extend beyond the one mile threshold of the roadway segment of the incident scene. Furthermore, the incident duration considered as the time threshold is not a good representative of the duration of incident impacts because the clearance times of impacts may vary, depending on such variables as traffic volumes, speed, and capacity. Clearly, static thresholds lack accuracy and will certainly lead to unreliable conclusions.

Similarly, studies in (41) conclude that more than 15 percent of crashes might be secondary. However, as in (23), secondary incidents in (41) were defined using static thresholds using clearance time of incident and impacted segment (queue) length. Furthermore, the difficulty in linking secondary incidents to primary incidents was pointed out in (41). Similarly, the author in (55) considered, as secondary incidents only those incidents that occur within the clearance time plus fifteen minutes and in the range of one mile in each direction from the primary location. Static thresholds were also used in (32) and (54) limiting time and space to clearance time and a two mile long queue in the same direction.

The time gap between primary and secondary incidents was studied in (55). Based on the data that was used in (55), it was noted that secondary incidents typically occurred within 20 minutes. However, this result can not be generalized since the spread of the various time periods was not analyzed. It was concluded in (55) that the relationship between a primary and secondary events must be studied further.

The static threshold that has been used so far in defining secondary incidents is depicted in Figure 10.1(a). It suggests that the incidents that fall within the rectangle formed by the

threshold, which is determined by the maximum queue clearance length and clearance time for the incident, are defined as secondary, for instance, Incidents A and C in Figure 1. However, this method can be improved since not all incidents that take place within these boundaries are secondary; for example, incident C is not secondary. Furthermore, not all secondary incidents are covered, such as incident B, which occurs within the queue caused by the primary incident. The idea behind counting accidents that are not secondary and ignoring secondary ones is that, on average, the number of actual secondary incidents is obtained. However, it is clear that the probability of incident C is not the same as that of incident B. Therefore, this method of averaging should be improved upon.

Sun, in (47) addressed the flaw of using static thresholds when defining secondary incidents and by proposing a dynamic progression curve representing the queue formed due to an incident. Depicted in Figure 10.1(b) is the progression curve of the queue length as a result of incident-related congestion. The queue progression curve demonstrates the increase of the queue length formation and its decrease until the queue that is formed during incident duration is resolved or congestion is completely cleared. The peak of the curve indicates the incident clearance time and the maximum queue length. In (47), 5514 freeway incidents were analyzed, and it was found that static and dynamic thresholds can vary in incident definitions by 30 percent.

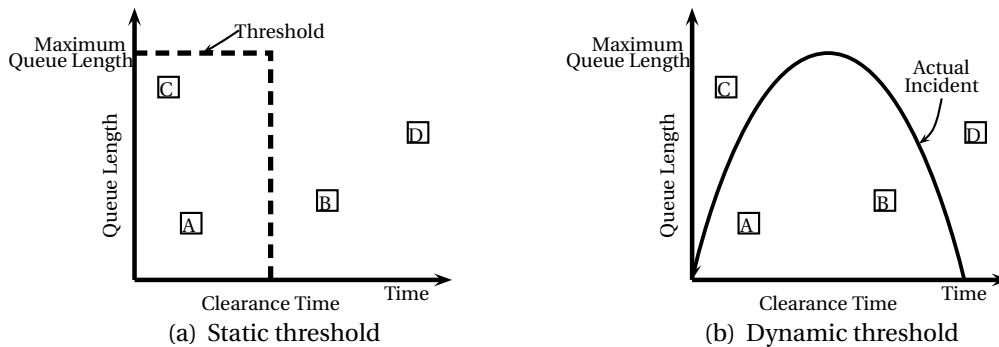


Figure 10.1: Freeway congestion progression curves due to traffic incidents

However, depending on such conditions as high volumes, the queue length might keep increasing after resolution of the primary incident is cleared or even after the resolution of the queue that is formed due to the incident. For instance, traffic volume can be sufficiently high such that the queue forms faster than it dissipates, as depicted in Figure 10.2. In other words, the back of the queue moving faster than the front. Furthermore, a progression curve of the rubbernecking effect was not addressed in (47).

In this study, a dynamic progression curve is developed for both directions, the incident direction and the opposite direction. In the next section, we will demonstrate through snapshots of a video of an incident that occurred near Seattle, WA, how the analysis of the static and dynamic progression curves can be enhanced.

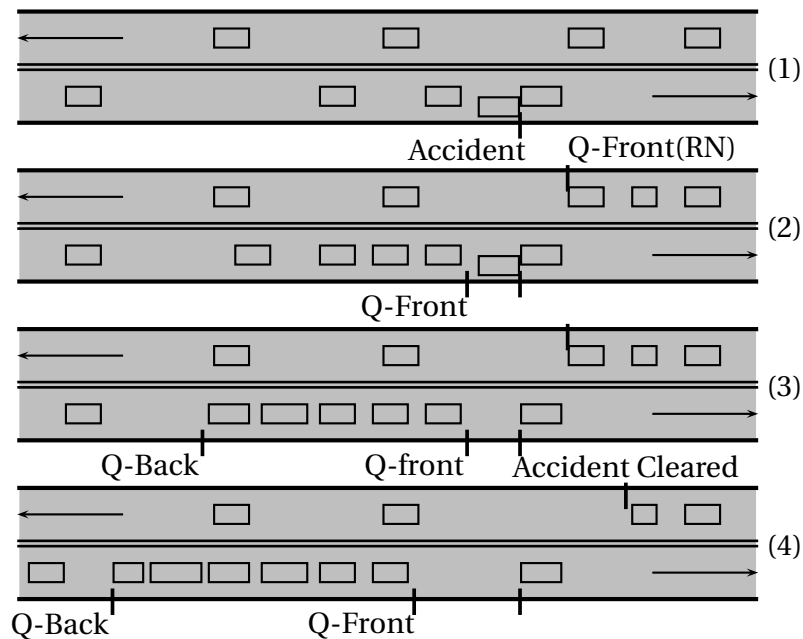


Figure 10.2: Operational implications of freeway incidents

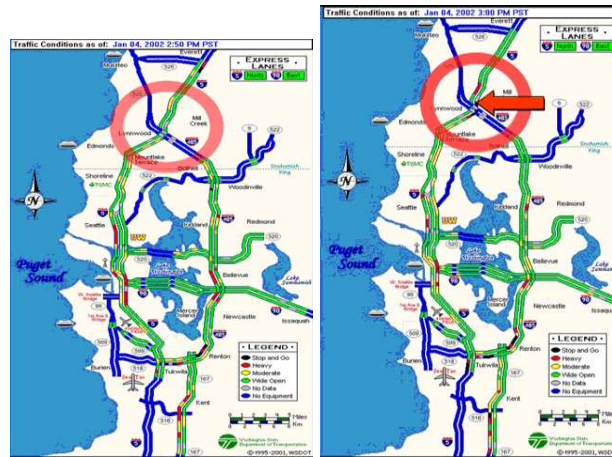
10.3 Case Study Video

The traffic behavior described in Figure 10.2 can be easily seen in this case study. This video was obtained from the Traffic Operation Center in north Seattle. It describes an incident that occurred on January 4, 2002 at 2:55 p.m. at the Interstate I-5 and I-405 Interchange near Linwood, as shown on 10.3(a). The green color indicates normal traffic flow at or near speed limit, the yellow signifies traffic flow below the speed limit, red illustrates heavy congestion, and blue indicates a segment that is not instrumented.

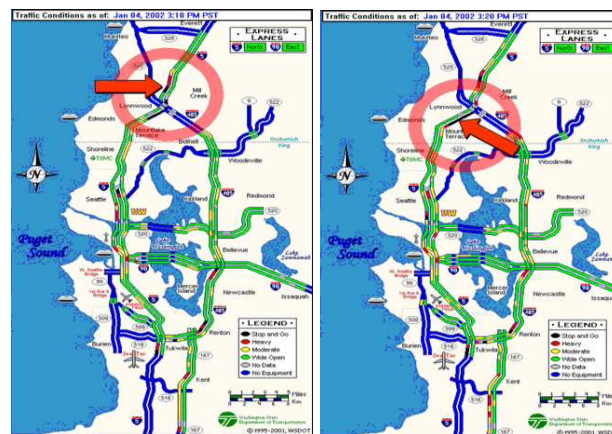
At 2:55 p.m., an accident occurred on the I-5 freeway near the interchange, as illustrated by the arrow in Figure 10.3(b). A substantial queue formed within a few minutes after the incident occurred. The impact of the primary accident is also seen by the traffic flowing in the opposite direction, as depicted in Figure 10.3(c).

The “rubbernecking” effect, caused by the emergency lights on the emergency vehicles caused a queue length of 2.3 miles. After approximately 10 minutes, the backup in the northbound lane in the direction of the accident extended to over 12 miles as shown in Figure 10.3(d).

Even though no secondary incidents occurred in this video, it clearly shows the large dynamic impact of a freeway incident in both directions. If another incident would have occurred at 3:40 p.m., for example, it would not have been considered a secondary incident.



(a) I-5 and I-405 near Linwood (b) An accident occurred at 2:55 pm



(c) Queue length of 2.3 "rubbernecking" (d) Twelve miles of back up at 3:20 PM

Figure 10.3: The I-5 and I-405 interchange near Linwood north of Seattle, WA

According to the conventionally used definition of secondary events, the static thresholds are less than 1 mile and clearance time plus fifteen minutes. The accident scene almost was cleared 35 minutes after the incident occurrence, and at that time, the queue had extended to about 10 miles. The impact continued, as shown in Figure 10.4. The incident was completely cleared at 3:40 p.m.; however, the queue continued to grow. At 4:40 p.m., the crash had been cleared for over an hour and yet the traffic was congested in northern King County, about 12 miles away from the original crash scene. This is a very common situation in peak periods, where drivers come to a stop in the middle of the freeway even without any apparent events. Normally, an earlier incident is the cause of such situations, which should be considered as secondary congestion.

The standard static and dynamic progression curves both should be enhanced to describe the operational implications of the primary incident in this case study, such as rubber necking and the dynamical movement of the front and back of the queue. The static threshold would miss the real secondary incidents because the queue length extended beyond the 1 mile or 2 mile limit. The dynamic threshold would also miss real secondary incidents since

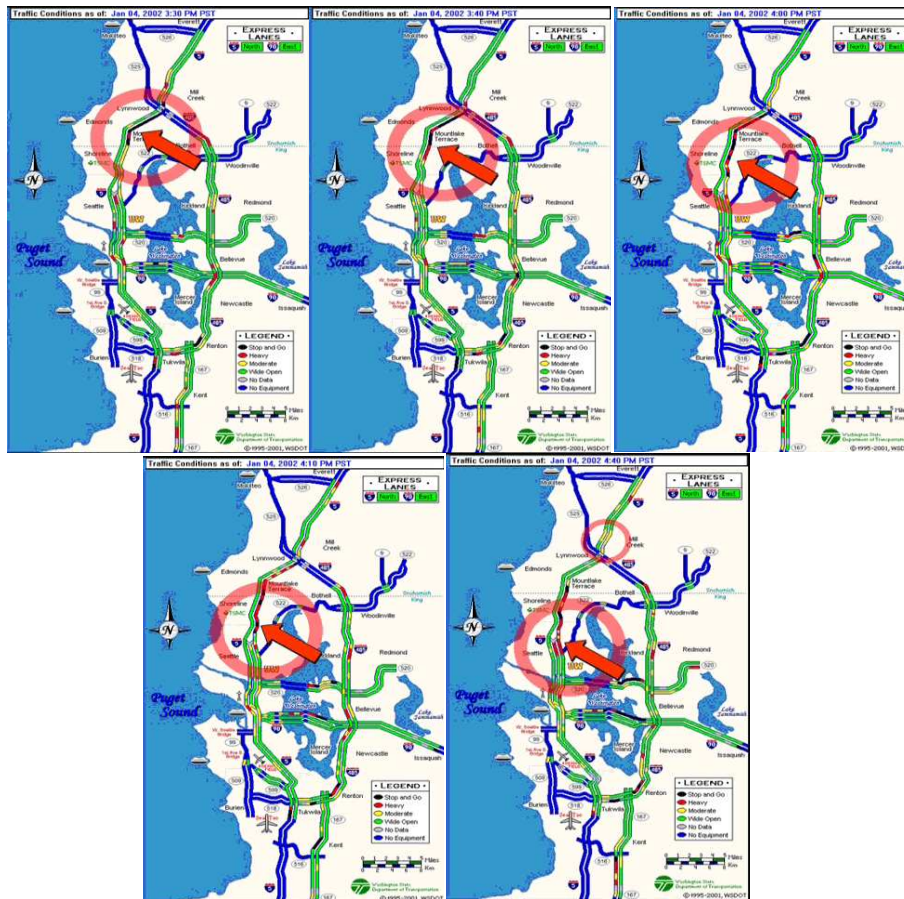


Figure 10.4: Progression of the queue after the incident clearance extends to twelve miles even after an hour from clearance

the queue kept increasing even after the incident was resolved. In other words, the back of the queue was moving faster than the front.

10.4 Simulations

Data regarding exact queue lengths formed upon incident occurrences generally is not available and also is difficult to obtain. The case study in the previous section motivated researchers to simulate incident scenes. In order to fully analyze impacts of incidents under various circumstances, simulations were carried out using a modeling tool for dynamic system simulation, VisSim. Various parameters, such as traffic volume, speed limits, and number of lane obstructions, were taken into consideration to carryout the essence of the various temporal and spatial effects observed. Actual Las Vegas traffic volumes from the I-15 are used in these simulations. The model of this freeway, shown in Figure 10.5, consists of a two-way segment as well as four lanes in each direction.

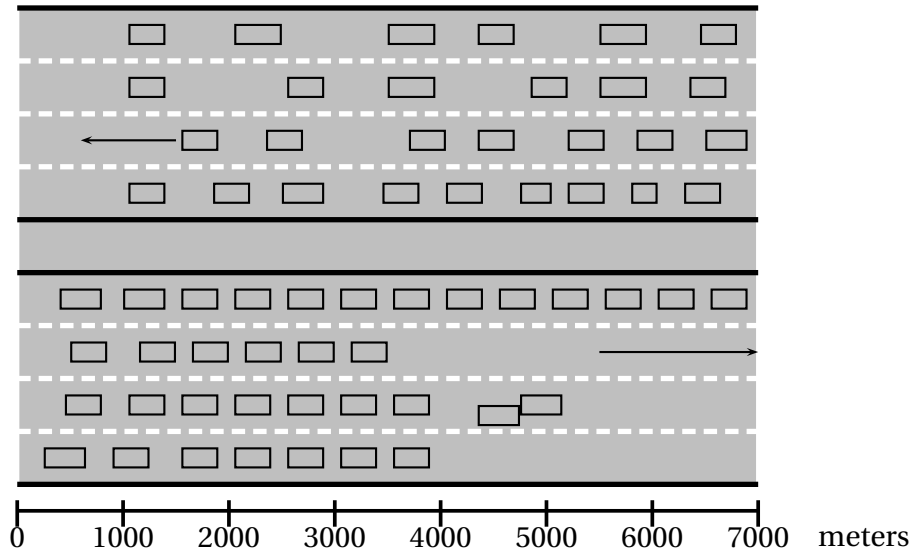


Figure 10.5: Section of freeway showing the location of incident

10.4.1 Parameters Calibration and Validation

Using VISSIM, traffic volumes are necessary in order to estimate the queue lengths. In order to make the simulation results more meaningful and behave much closer to the real-time scenarios, real-time traffic data with such details as traffic variation at different locations and change of traffic demand according to the time of day is taken into consideration. Annual Average Daily Traffic (AADT) and Monthly Average Daily Traffic (MADT) data are used to estimate traffic volumes according to the time of the day.

AADT gives the average traffic volume per day. Since traffic volumes vary greatly during the day, moderate and low traffic volumes are estimated from an AADT data. Therefore, this data can not be used for estimation of peak hours. MADT data consists of hourly traffic volumes at particular locations. This data is suitable for obtaining peak, moderate, and low traffic volumes. The Least Mean Square (LMS) method is used to estimate peak, moderate, and low traffic volumes from the simulated data.

For creating this simulation, calculations were performed based on the LMS in order to estimate peak, moderate, and low traffic volumes. The results are presented in Table 10.1.

Traffic Level	Linear Fit	R^2 (%)	Estimated Volume (vph)
Peak	$y = 5221.6119 + 1.02(x_i)$	84.6	12000
Moderate	$y = 631.53 + 1.04(x_i)$	70.6	9000
Low	$y = -839.375 + 0.346(x_i)$	78.9	2000

Table 10.1: Estimation of peak, moderate, and low traffic volumes for calibration of simulations

The average traffic volume on a freeway using AADT data is observed to be 8000 vehicles per hours (vph). Therefore using the least mean square estimation the peak, moderate, and low traffic volumes are estimated to 12000, 9000, and 2000, respectively.

10.4.2 Simulation of Congestion in the Same Direction as the Primary Incident

An interesting effect observed in the Seattle incident is the increase of queue length after the incident is cleared. This congestion might not be recognized as an impact of the cleared primary incident; yet, it is. Therefore any incidents that fall within this type of congestion pattern must be considered as secondary. Using simulations, we attempted to capture these types of effects. 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 were 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 vph and an incident clearance time of 30 minutes. Table 10.2 shows the location in miles of the front and back of the queues formed; this was measured from a static point with respect to time, in minutes. The values in bold represent the clearance time, with the associated location of the queue.

Time	12000vph		9000vph		2000vph	
	Qfront	Qback	Qfront	Qback	Qfront	Qback
6	6.27	6.27	6.27	6.27	6.27	6.27
8	6.27	6.03	6.27	6.13	6.27	6.18
10	6.27	5.76	6.27	5.98	6.27	6.08
12	6.27	5.47	6.27	5.81	6.27	5.95
14	6.27	5.19	6.27	5.64	6.27	5.83
16	6.27	4.9	6.27	5.45	6.27	5.7
18	6.27	4.6	6.27	5.26	6.27	5.53
20	6.27	4.31	6.27	5.05	6.27	5.41
22	6.27	4	6.27	4.9	6.27	5.3
26	6.27	3.43	6.27	4.57	6.27	5.1
28	6.27	3.16	6.27	4.4	6.27	4.98
30	6.27	2.9	6.27	4.23	6.27	4.9
32	6.27	2.65	6.27	4.05	6.27	4.75
34	5.87	2.39	5.92	3.89	5.8	4.63
36	5.29	2.12	5.39	3.73	5.31	4.55
38	4.72	1.89	4.83	3.55	4.8	4.48
40	4.18	1.64	4.29	3.38	4.33	4.33
44	3.09	1.16	3.21	3.06	4.33	4.33
46	2.56	0.91	2.95	2.92	4.33	4.33
48	2.02	0.69	2.95	2.92	4.33	4.33
50	1.47	0.53	2.95	2.92	4.33	4.33
52	0.93	0.3	2.95	2.92	4.33	4.33
54	0.40	0.18	2.95	2.92	4.33	4.33
55	0.18	0.6	2.95	2.92	4.33	4.33

Table 10.2: Tracking the locations of front and back of the queue in incident direction

Simulation results show that the queue length increases for 13 minutes after the incident is cleared, and its location moved to approximately 1 mile from the incident scene. Note that

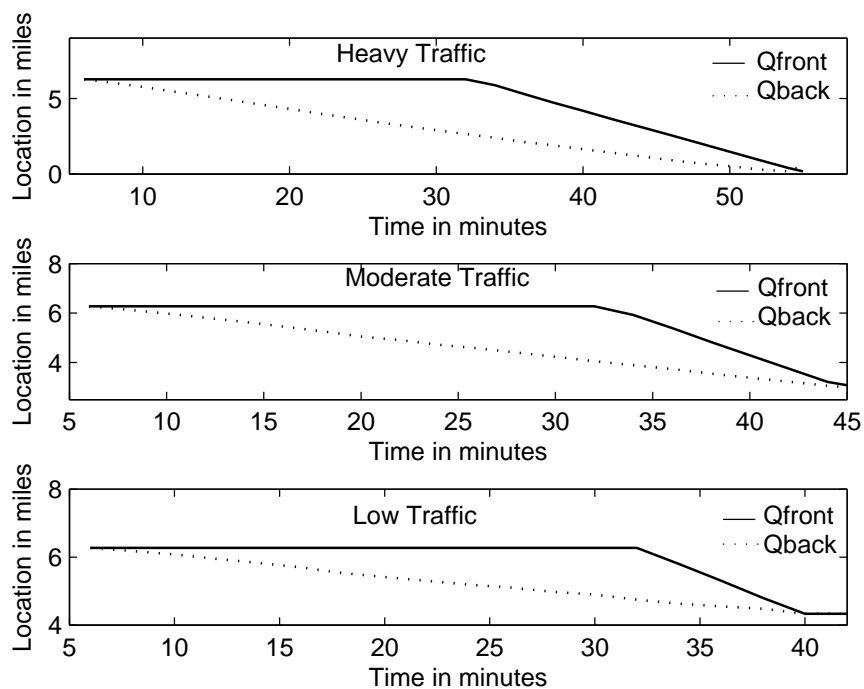


Figure 10.6: Queue formed in the direction of primary incident

such congestion would not have been considered secondary, according to previous definitions (less than one mile). However, it is found to occur purely due to the primary incident.

The graph in Figure 10.6 shows the movement of the front and back of the queue as the time progresses when two lanes are blocked for different traffic volumes. This graph shows that until the accident is cleared, the front of the queue is constant and back of the queue is gradually increasing. Once the accident is removed the front of the queue gradually clears; at the same time, the back of the queue increases at the same rate. After the incident was removed, it was observed that the queue kept increasing for 22 minutes, with the back of the queue reaching 1.79 miles. Furthermore, the queue kept increasing even after the clearance of the queue that was formed until clearance time; this indicates that the standard which dynamic progression model would miss secondary incidents.

10.4.3 Simulation of the Effect of the Primary Incident on the Opposing Traffic: Rubbernecking

As discussed in previous sections, the impact of primary incidents on the opposite side of the freeway from the primary incident must also be studied. It is a common phenomenon for the opposing traffic to slow down upon approaching an incident scene, usually out of curiosity or even due to cautiousness. The traffic in the opposite direction is affected by a certain factor known as rubbernecking and 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. Furthermore, different traffic volumes

Time	12000vph		9000vph		2000vph	
	Qfront	Qback	Qfront	Qback	Qfront	Qback
2.5	3.15	3.24	3.15	3.23	3.15	3.15
3.5	3.15	3.25	3.15	3.24	3.15	3.24
4.17	3.15	3.42	3.15	3.36	3.15	3.2
5	3.15	3.36	3.15	3.33	3.15	3.33
5.83	3.15	3.49	3.15	3.37	3.15	3.19
8.33	3.15	3.39	3.15	3.38	3.15	3.24
10	3.15	3.43	3.15	3.52	3.15	3.15
11.67	3.15	3.51	3.15	3.27	3.15	3.27
13.33	3.15	3.37	3.15	3.3	3.15	3.27
15	3.15	3.5	3.15	3.38	3.15	3.28
18.33	3.15	3.64	3.15	3.26	3.15	3.15
20	3.15	3.58	3.15	3.39	3.15	3.28
21.67	3.15	3.44	3.15	3.39	3.15	3.26
23.33	3.15	3.64	3.15	3.25	3.15	3.36
25	3.15	3.55	3.15	3.32	3.15	3.28
26.67	3.15	3.64	3.15	3.3	3.15	3.28
28.33	3.15	3.57	3.15	3.28	3.15	3.29
30	3.15	3.83	3.15	3.32	3.15	3.35
31.67	3.15	3.51	3.15	3.25	3.15	3.37
32.5	3.15	3.44	3.15	3.22	3.15	No Congestion

Table 10.3: Congestion patterns on the opposite side of the freeway due to rubbernecking for heavy, moderate, and low traffic volumes

are also taken into account to study the effects and congestion behavior for low (2000vph), medium (9000vph) and heavy traffic (12000vph).

Simulation results, shown in Table 10.3, indicate that the congestion can increase up to one mile, based on the traffic. For this study, the speed of the opposing traffic was reduced to 30 mph; generally, however, this would vary. This effect, depending on the values of the various parameters, might continue even after the incident is removed.

The graph 10.7(a) 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 fluctuates due to the stochastic nature of the arrivals. The maximum queue formed in this simulation is approximately 0.25 mile.

The graph in Figure 10.7(b) demonstrates the effect of congestion for moderate traffic. The front location is where the drivers are distracted, which may lead to vehicles slowing down. Furthermore, the graph depicts the location of the back of the queue, which fluctuates with respect to the traffic volume. The maximum queue reached is 0.7 miles in length for a moderate traffic. The effect of congestion at high traffic volumes is depicted in the graph in Figure 10.7(c). In this case, the maximum queue reached is 1.5 miles.

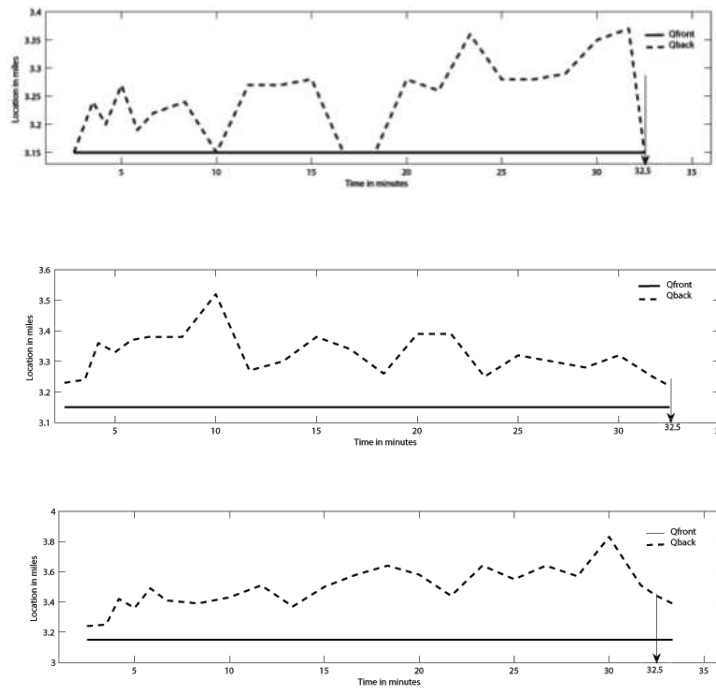


Figure 10.7: Congestion patterns on the opposite side of the freeway due to rubbernecking for low, moderate, and heavy traffic volumes

10.4.4 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 leads to the resolution of the queue. As the congestion clears up, the distraction point for the traffic on the other side of the freeway also changes. A simulation was performed to study the dynamic nature of the freeway of the distraction point as the queue is cleared, and the results are shown in Table 10.4. The location of front and back of the queue were tracked in both directions, and took into consideration heavy traffic (12000vph) in the opposite direction. The graph in Figure 10.8, depicts the movement of the congestion point or the distraction point with respect to the dynamics of the queue in the direction of the accident.

10.5 Results and Discussion

Table 10.5 summarizes the results of calculating and tabulating, the rates of various scenarios at which the queue lengths increased or decreased for every minute.

The parameters required for the simulations, such as traffic volumes, speed limits and rubbernecking factors, were represented on I-15 in the Las Vegas region. Taking into consideration various volume levels, it was observed that the results varied greatly. Queue length varied from one fourth of a mile to one mile, and the clearance time of the queue that, formed after incident clearance varied from three to five minutes. Simulations were carried out on

Time	Location			
	Accident direction		Opposite direction	
	Qfront	Qback	Qfront	Qback
5.67	3.15	3.14	3.15	3.24
7.33	3.15	3.09	3.15	3.25
10.67	3.15	2.95	3.15	3.51
12.33	3.15	2.85	3.15	3.4
14	3.15	2.77	3.15	3.48
15.67	3.15	2.7	3.15	3.47
17.33	3.15	2.6	3.15	3.53
19	3.15	2.52	3.15	3.67
20.67	3.15	2.46	3.15	3.6
22.33	3.15	2.37	3.15	3.55
24	3.15	2.3	3.15	3.54
25.67	3.15	2.21	3.15	3.61
27.33	3.15	2.13	3.15	3.63
29	3.15	2.05	3.15	3.6
30.67	3.15	1.97	3.15	3.83
32.33	3.15	1.91	3.15	3.61
34	3.15	1.82	3.15	3.49
35.67	3.15	1.73	2.93	3.51
37.33	2.81	1.64	2.57	3.36
39	2.49	1.57	2.47	3.07
40.67	2.15	1.47	2.05	2.75
42.33	1.82	1.39	1.76	2.3
44	1.46	1.31	1.83	2.18
45.33	1.24	1.24	1.45	1.45

Table 10.4: Dynamic movement of distraction point on the other side of the freeway

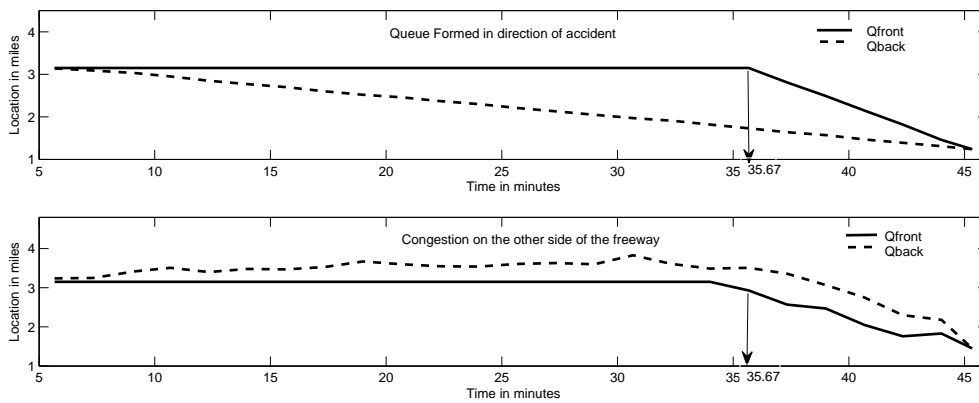


Figure 10.8: The dynamic movement of the congestion point on the other side of the freeway

the opposite direction of the freeway with reduced speeds of 30 mph, representing a certain distraction level or rubbernecking effect. Each of these cases was examined using three different traffic volumes: low (2000 vph), medium (9000 vph), and heavy (12000 vph). The

Volume	Queue	accident	Queue	Dynamic queue
	lanes	4	speed	30
				Dynamic point
12000	inc	220	110	410
	dec	410	350	–
9000	inc	163	77	–
	dec	446	325	446
2000	inc	67	30	–
	dec	450	220	450

Table 10.5: Rate of increase and decrease of the queue considering different scenarios

dynamics of congestion in the opposite direction was also simulated by tracking the distraction point, since this plays a crucial role in defining secondary incidents. Once the incident was removed, the location changed for the queue occurring in the same direction as the accident. Therefore, the location of the distraction point on the other side of the freeway also changed. This dynamic effect must be considered while determining the spatial thresholds for identifying secondary incidents. The graph in Figure 10.8 shows how the queue caused by distraction moves with respect to the original queue. To estimate traffic related parameters, we obtained generalized relations by using the least mean square estimation method. These relations give the estimates for peak volumes, moderate volumes, and low traffic volumes from an average traffic volume.

From VisSim simulation runs, we obtained the rate at which the queue length formed for the peak traffic volume in both directions. We compared the rate of decreasing queue length in both directions, and also the rate of movement of the distraction point as the queue cleared. Similarly, the rate at which the queue length formed for the moderate traffic volume in both directions was calculated. The queue length decreased in both the directions at rates of 450 and 325 m/minute. As the queue gets cleared, the rate of movement of distraction point is given as 450 meters(m)/minute.

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 directions at the rates of 50 and 220 m/minute. The rate of movement of distraction point as the queue gets cleared was 450 m/minute.

Figure 10.9 is the proposed model for identifying secondary incidents on freeways. Incident “A” in this figure can be identified by three curves: static, dynamic, and moving dynamic. Incident “B” can be identified by only the dynamic and moving dynamic methods. However, the dynamic approach will not be able to recognize incidents that take place within the secondary congestion, such as incident “C” or the rubbernecking effect, such as incident “E”. Secondary incidents contribute to the increase of the queue length within which the occurrence of any incident can also be considered as secondary to the original incident, such as “D”. Notice that the front of the queue in the rubbernecking region could vary with respect to the primary incident region. The area between the dashed line and the upper solid line in the rubbernecking region represents the range of possibilities for the front of the queue in Figure 10.9.

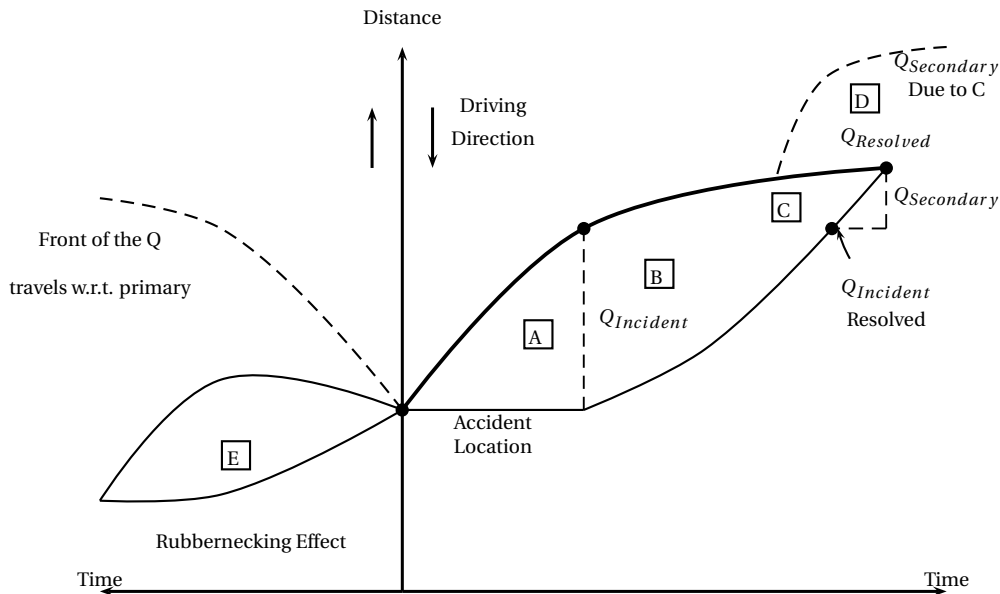


Figure 10.9: Proposed moving dynamic progression curve for incident related freeway congestions

10.6 Conclusions

In this study, the full operational impacts of freeway incidents was analyzed through simulations as well as by means of a case study. In this section, the dynamic nature of incident-related congestions as well as secondary congestions were explored. It was found that depending on traffic conditions, congestion in the same direction of the incident may extend far beyond the queue formed during clearance time. In other words, the front of the queue propagates upstream, which leads to secondary congestion and increases the likelihood of secondary accidents. Moreover, an incident may cause distraction on a highway (rubbernecking), which usually leads to the formation of another queue in the opposite direction of the primary incident. The congestion caused by this queue can have considerable delays, and increase the probability of secondary accidents in the opposite direction. As demonstrated in this study, the spatial and temporal range of a freeway incident effects often extend well beyond the static thresholds that have been used in the past for secondary incident investigations. Hopefully, this provides a strong motivation to initiate theoretical modeling so that the full implications of primary and secondary freeway incidents can be studied.

Chapter 11

Bayesian Safety Analyzer

11.1 Introduction

This section presents a very important tool in data integration, analysis, and probability theory. Bayesian theory is used in order to build a probabilistic data structure that can be used to extract likelihood information about various pieces of parameters that are updated through the enormous amount of data. A given data set usually has a number of attributes where the relationship between them is not well defined. When constructing a Bayesian structure over the available data set, each attribute becomes a node. The links between the nodes can be determined by the nature of the problem, for instance bad weather conditions can impact the probability of incidents thereof congestion. This leads to a nodal structure that has a topological order where ancestor nodes must precede descendant nodes. The Bayesian Safety Analyzer (BSA) is designed based on an integration of multiple traffic and crash data sources. The BSA tool allows structuring the available data into a Bayesian Network. Based on the content of the data, the occurrence likelihood of different components in the system can be extracted. Data for the BSA networks developed herein is obtained from Freeway and Arterial System of Transportation (FAST), Nevada Highway Patrol (NHP), and Nevada Department of Transportation (NDOT).

11.2 Available Data

The BSA structure presented in this study is based on traffic data as well as crash data from multiple sources. The data is collected from multiple agencies FAST, NHP, and NDOT. FAST collects traffic data on the freeways, mainly the I-15. In addition, FAST collects accident data observed through their video cameras. Additional Crash or accident data is also collected from NHP and NDOT. Obtaining crash data from multiple sources is important since different agencies collect different attributes. For instance, FAST is the only agency that collects the number of lane closure; however, FAST does not collect other information such as weather conditions or clearance times.

The following is a list of the various attributes collected by the different agencies:

- **FAST detector data:** Time stamp, Location, Cumulative Volume, Volume by Vehicle size, Speed.

- **FAST accident compile:** Date and time, Location, Lanes Blocked.
- **NHP:** Date and time, Location, Incident Type, Receive Time, Dispatch Time, Enroute Time, Onsite Time, Clearance Time
- **NDOT Crash Data:** Date and time, Location, Weather, Number of vehicles, Type of vehicles.

11.3 Bayes' theorem

In probability theory, Bays theorem is used to calculate the inverse conditional probability or the posterior probability of a certain event A given another event B . Bay's theorem requires the knowledge of the prior probabilities of A and B (also called marginal probability) and the likelihood of A given B which is obtained by calculating the conditional probability of B given A .

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

In order to calculate the conditional probabilities, the following equation is used:

$$P(A|B) = \frac{P(A \cap B)}{P(B)}$$

Where:

$P(A)$: is the prior probability of A.

$P(B)$: is the prior or the marginal probability of B.

$P(A|B)$: is the posterior probability of A given B.

$P(B|A)$: is the likelihood of A given B.

11.4 Proposed Bayesian Safety Analyzer Model

The Bayesian model in Figure 11.1 is formed via eight hierarchical levels. The increase of hierarchy level may reduce direct dependencies between parents' nodes and immediate children which implies simpler distribution tables for each node. However, the number of hierarchical levels is constrained by the nature of the problem being modeled since certain parameters directly depend on multiple parameters simultaneously.

The tables below define the probability distributions for all the parameters and their states in the Bayesian model. The probability distributions describe the direct relationship between parents nodes and immediate children nodes.

Definition:

Let S be a finite parents space containing n members given by s_1, s_2, \dots, s_n . $\forall s_i \in S, m(s_i) \equiv$ the number of states each parent s_i can take.

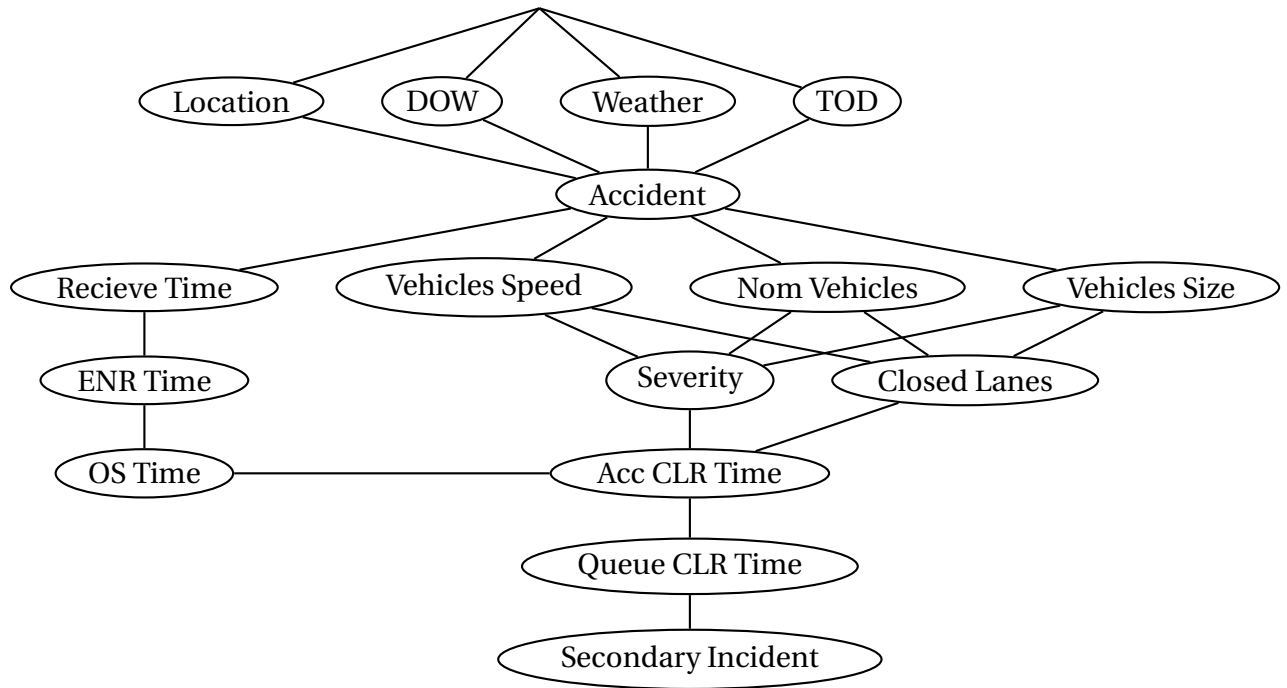


Figure 11.1: Proposed Bayesian Model

Table 11.1: Terms Definitions

Term	Definition
TOD	Time of day
DOW	Day of week
ENR Time	Enroute time
OS Time	Onsite time
CLR Time	Clearance Time

Proposition:

The number of all possible combinations of states for which the children’s probability distribution must be defined is given by:

$$m(S) = \prod_{i=1}^n m(s_i)$$

This clearly indicates that the distribution tables’ size increase tremendously for each node based on the number of parents nodes and the number of their states. Initially, uniform distribution is assumed for all the parameters. The Bayesian structure can learn using data and accordingly adjust the given distributions. The distribution tables for the BSA model introduced in this work are presented in Tables 11.3(a), 11.3(b), 11.3(c), 11.4(a), 11.5(a), 11.5(b), 11.6(a), and 11.6(b). The hierarchal structure of the BSA has eight stages corresponding to the data presented in Table 11.2.

11.5 Bayesian Inference

Bayesian inference is a method of statistical inference. Data is used to calculate the probability that a hypothesis may be true, or it could be used to update its previously calculated probability. Bayesian inference uses the prior probability over a certain hypotheses to determine the likelihood of a particular hypothesis given some observed data.

11.6 Constructing Bayesian Model and Simulations in MATLAB - FullBNT-1.0.4

11.6.1 Nodes and Relations Assignment

The MATLAB code in Program 9 demonstrates the Bayesian construction of the analyzer through nodes assignment and their relations.

When displaying the network at this stage, the following is obtained:

```
bnet =  
equivclass: [12345678910111213141516]  
dnodes: [12345678910111213141516]  
observed: [12345678910111213141516]  
names: [1x1assocarray]  
hidden: [1x0double]  
hidden_bitv: [0000000000000000]  
dag: [16x16double]  
nodesizes: [2232222432444442]  
cnodes: [1x0double]  
parents: 1x16cell  
members_of_equivclass: 1x16cell  
CPD: 1x16cell  
rep_of_class: [12345678910111213141516]  
order: [43215987121161013141516]
```

11.6.2 Distribution Assignment

The code in Program 10 performs the distribution assignment of the nodes as well as creates an inference.

11.6.3 Marginal Distribution Computation

In order to demonstrate how to calculate marginal distributions, consider the example where the evidence consists of the fact that ‘SecondaryIncident’ takes the value 2, meaning that a secondary incident has occurred. Then, to compute the probability that ‘Severity’ is at level 2, indicating injury, given that ‘SecondaryIncident’ is 2 the code in Program 11 is performed. Running the code gives $p = 0.25$ which makes sense since the distributions are uniform by assumption. The graph in Figure 11.2 displays the marginal distributions of the ‘Severity’ being at level 1, 2, 3, or 4, respectively given that a secondary incident has occurred.

Program 9 Bayesian Structure Construction

```
N = 16;
dag = zeros(N,N);

%Assign nodes in the Bayesian Structure
Location = 1; DOW = 2; Weather = 3; TOD = 4;
Accident = 5;
RecieveTime = 6; VehiclesSpeed = 7; NomVehicles = 8; VehiclesSize = 9;
ENR = 10; Severity = 11; ClosedLanes = 12;
OSTime = 13;
AccCLRTime = 14;
QueueCLRTime = 15;
SecondaryIncident = 16;

%Assign relations between nodes
dag(Location,Accident)=1;
dag(DOW,Accident)=1;
dag(Weather,Accident)=1;
dag(TOD,Accident)=1;
dag(Accident,[RecieveTime VehiclesSpeed NomVehicles VehiclesSize])=1;
dag(RecieveTime,ENR)=1;
dag(VehiclesSpeed,[Severity ClosedLanes])=1;
dag(NomVehicles,[Severity ClosedLanes])=1;
dag(VehiclesSize,[Severity ClosedLanes])=1;
dag(ENR,OSTime)=1;
dag(Severity,AccCLRTime)=1;
dag(ClosedLanes,AccCLRTime)=1;
dag(OSTime,AccCLRTime)=1;
dag(AccCLRTime,QueueCLRTime)=1;
dag(QueueCLRTime,SecondaryIncident)=1;

%Determine size of nodes
discrete_nodes = 1:N;
node_sizes = [2 2 3 2 2 2 2 2 4 3 2 4 4 4 4 2];
onodes = 1:N;

%Make BayNet
bnet = mk_bnet(dag, node_sizes, 'names', 'Location', 'DOW', 'Weather', 'TOD','Accident',
'RecieveTime','VehiclesSpeed','NomVehicles','VehiclesSize','ENR', 'Severity','ClosedLanes','OSTime',
'AccCLRTime','QueueCLRTime','SecondaryIncident', 'discrete', discrete_nodes, 'observed', onodes);

%Display BayNet
bnet
```

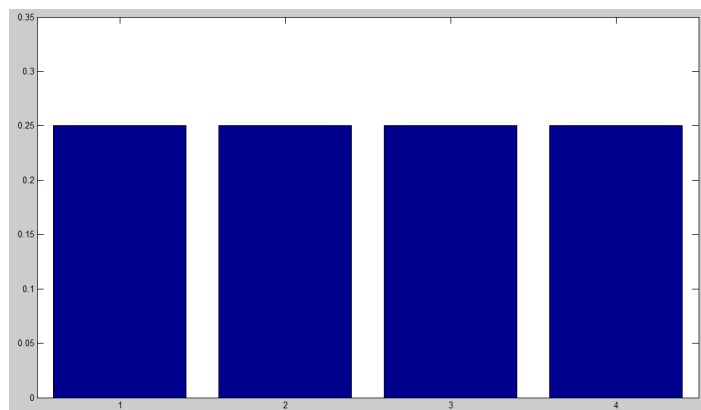


Figure 11.2: Marginal Distributions

Program 10 Distribution assignment of nodes

```
%Assigning Distribution
bnet.CPDLocation= tabular_CPD(bnet, Location, [0.5 0.5]);
bnet.CPD DOW      = tabular_CPD(bnet, DOW, [0.5 0.5]);
bnet.CPDWeather  = tabular_CPD(bnet, Weather, [0.3 0.3 0.4]);
bnet.CPD TOD     = tabular_CPD(bnet, TOD, [0.5 0.5]);
bnet.CPD Accident= tabular_CPD(bnet, Accident, [0.5 0.5 0.5
0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5
0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5]);
bnet.CPD RecieveTime= tabular_CPD(bnet, RecieveTime, [0.5 0.5 0.5 0.5]);
bnet.CPD VehiclesSpeed= tabular_CPD(bnet, VehiclesSpeed, [0.5 0.5 0.5 0.5]);
bnet.CPD NomVehicles  = tabular_CPD(bnet, NomVehicles, [0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25]);
bnet.CPD VehiclesSize = tabular_CPD(bnet, VehiclesSize, [0.33 0.33 0.33 0.33 0.33 0.33]);
bnet.CPD ENR          = tabular_CPD(bnet, ENR, [0.5 0.9 0.5 0.1]);
bnet.CPD Severity    = tabular_CPD(bnet, Severity, [0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25]);
bnet.CPD ClosedLanes = tabular_CPD(bnet, ClosedLanes, [0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25]);
bnet.CPD OSTime      = tabular_CPD(bnet, OSTime, [0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25]);
bnet.CPD AccCLRTime  = tabular_CPD(bnet, AccCLRTime, [0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25
0.25]);
bnet.CPD QueueCLRTime = tabular_CPD(bnet, QueueCLRTime, [0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25]);
bnet.CPD SecondaryIncident= tabular_CPD(bnet, SecondaryIncident, [0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5]);

%creating inference
engine = jtree_inf_engine(bnet);
```

11.7 Bayesian Parameter Learning

There are four types of parameter estimation:

1. **Fully observed point estimate:** Maximum likelihood parameter estimation from com-

Program 11 Distribution assignment of nodes

```
%creating inference
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
engine = jtree_inf_engine(bnet);

%Computing Marginal Distributions
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%The evidence consists of the fact that SecondaryIncident=2
%All the other nodes are hidden (unobserved)
evidence = cell(1,N);
evidenceSecondaryIncident = 2;

%add the evidence to the engine.
[engine, loglik] = enter_evidence(engine, evidence);

%compute p=P(Severity=2|SecondaryIncident=2) as follows.
marg = marginal_nodes(engine, Severity);
marg.T
p = marg.T(2)

%add the evidence that 3 lanes were closed
evidenceClosedLanes = 3;
[engine, loglik] = enter_evidence(engine, evidence);
marg = marginal_nodes(engine, Severity);

% Find p = P(Severity=2|SecondaryIncident=2,ClosedLanes=3)
p = marg.T(2)

%plot a marginal distribution over a discrete variable as a barchart
bar(marg.T)
```

plete data, command: *learn – params*

2. **Partially observed point estimate:** Maximum likelihood parameter estimation with missing values, command: *learn – params – em*
3. **Fully observed full Bayesian:** (Sequential) Bayesian parameter updating from complete data, *bayes – update – params*
4. **Partially observed full Bayesian:**Not supported

Fully observed indicates that all the variables are observed, whereas partially observed indicates that there is missing or hidden data. Full Bayesian computes the full posterior over the parameters. However, point estimate computes Maximum Likelihood or a Maximum A Posteriori.

11.7.1 Loading Data

Data is needed in order to perform parameter learning on the Bayesian structure. For testing purposes, data can be generated using forward sampling. However, in this study, a sample data file is created which corresponds to the parameters and values specified in Tables 11.2. Various file formats are supported including txt and xls. The data is then loaded as shown in Program 12 and is used to update the distributions of each parameter in the Bayesian structure. The original data must be processed and formatted in order to be read by the structure.

Program 12 Distribution assignment of nodes

```
%data = load('DataRdTr.txt', '-ascii');
data   = xlsread('AccidentPredict.xls')

ncases = size(data, 1) % each row of data is a training case

cases  = cell(16, ncases);

cases([1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16], :) =
num2cell(data') % each column of cases is a training case

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

11.7.2 Maximum Likelihood Parameter Estimation from Complete Data

Program 13 demonstrates how parameter learning is accomplished. After the data is loaded from the sample file, it is used to find the maximum likelihood estimates. The learnt parameters can be viewed using a MAT LAB trick as shown in the program below. For instance, after updating the structure in this study using a sample data file of 20 entries, the following is obtained when node 4 is viewed:

```
1 : 0.4500
2 : 0.5500
```

Note that the distribution is not uniform anymore for this node which indicates that the distributions of the nodes are updated using the new data.

11.7.3 Partial Parameter Learning

When data is incomplete or has missing values, the Maximum Likelihood Estimates (MLEs) values are computed using the EM algorithm. An inference algorithm is used in order to compute the expected sufficient statistics as shown in Program 14. Depicted in Figure 11.3 is the plot of the log-likelihood at the i^{th} iteration.

Program 13 Distribution assignment of nodes

```
%Parameter Learning

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% find the maximum likelihood estimates of the parameters.

bnet3 = learn_params(bnet2, cases);

bnet3

%To view the learned parameters, we use a little Matlab hackery.

CPT3 = cell(1,N);

for i=1:N

    s=struct(bnet3.CPDi); % violate object privacy

    CPT3i=s.CPT;

end

%Here are the parameters learned for node 4.
disp(cpt(CPT34))
```

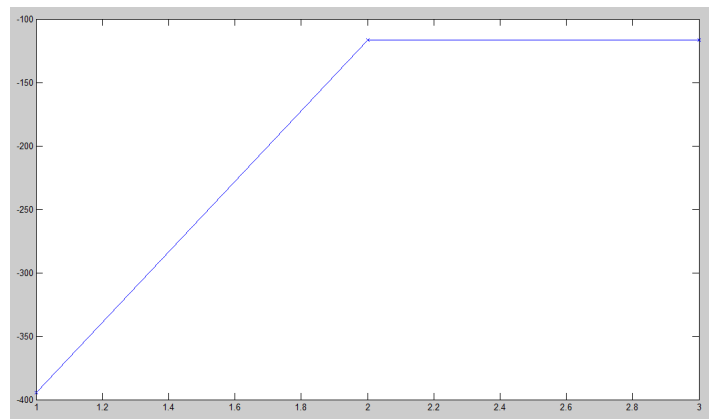


Figure 11.3: The log-likelihood at the i^{th} iteration

11.8 Conclusions

In this chapter, a Bayesian Safety Analyzer (BSA) is constructed based on various data sources including mainly crash data and traffic data. It is demonstrated how posterior probabilities can be computed and how data can be used to train the Bayesian structure composed of a large amount of parameters. Bayesian analysis is proved to be a very efficient probabilistic method for analyzing a large set of data in order to better estimate dependencies and likelihood of occurrence of various events.

Program 14 Distribution assignment of nodes

```
%Partial Parameter Learning
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
engine2 = jtree_inf_engine(bnet2);
max_iter = 10;
[bnet4, LLtrace] = learn_params_em(engine2, cases, max_iter);

%LLtrace(i) is the log-likelihood at iteration i. We can plot this as follows:
plot(LLtrace, 'x-')
```

Table 11.2: State Description of Parameters

Parameter	States Description	State	States Values
Location	Freeway or Arterial	Fr	2=Freeway, 1=Arterial
DOW	Weekday or Weekend	Wd	2= Weekday 1= Weekend
Weather	Rain, Fog, or Clear	Wth	3= Rain, 2= Fog, 1= Clear
TOD	Peak-hour or Regular	Pk	2=Peakhour, 1= Regular
Accident	Accident Occurred	Ac	2= True, 1= False
Receive Time	Informing response agency took greater than 1 minute	Rc	2= True, 1= False
Vehicles Speed	Vehicles involved were going higher than the speed limit	Vs	2= True, 1= False
Nom Vehicles	1, 2, 3, or more vehicles were involved	Vn	4= more than 3, 3= 3, 2= 2, 1= 1
Vehicles Size	At least one of the vehicles involved was of compact, medium, or large size	Vsz	Large= 3, Medium = 2, Compact= 1
ENR Time	The responding unit was on its way to the scene after more than 1 minute of being informed	En	2= True, 1= False
Severity	Property damage(Pd), Injury (In), Hit and Run (HR), or Fatality (Ft)	Pd	4= Ft, 3= HR, 2= In, 1= Pd
Closed Lanes	1, 2, 3, or all lanes were closed	L	4= All lanes, 3= 3, 2= 2, 1= 1
OS Time	The responding unit was on-scene within 5, 10, 15, or more minutes from being informed	Os	4 = more than 15 min, 3= 15, 2= 10, 1= 5
Acc CLR Time	Accident cleared within 30, 60, 90, or more minutes	Acl	4 = more than 90 min, 3= 90, 2= 60, 1= 30
Queue CLR Time	Queue due to accident was cleared within 30, 60, 90, or more minutes	Qcl	4 = more than 90 min, 3= 90, 2= 60, 1= 30
Secondary Incident	A secondary incident occurred	S	2= True, 1= False

Table 11.3: Hierarchical Initial Probability Distributions of Parameters

(a) Hierarchy level 1

P(Fr=2)	P(Fr=1)	P(Wd=2)	P(Wd=1)	P(Wth=3)	P(Wth=2)	P(Wth=1)	P(Pk=2)	P(Pk=1)
0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.5	0.5

(b) Hierarchy level 2

Fr	Wd	Wth	Pk	P(Ac=2)	P(Ac=1)
1	1	1	1	0.5	0.5
1	1	1	2	0.5	0.5
1	1	2	1	0.5	0.5
1	1	2	2	0.5	0.5
1	1	3	1	0.5	0.5
1	1	3	2	0.5	0.5
1	2	1	1	0.5	0.5
1	2	1	2	0.5	0.5
1	2	2	1	0.5	0.5
1	2	2	2	0.5	0.5
1	2	3	1	0.5	0.5
1	2	3	2	0.5	0.5
2	1	1	1	0.5	0.5
2	1	1	2	0.5	0.5
2	1	2	1	0.5	0.5
2	1	2	2	0.5	0.5
2	1	3	1	0.5	0.5
2	1	3	2	0.5	0.5
2	2	1	1	0.5	0.5
2	2	1	2	0.5	0.5
2	2	2	1	0.5	0.5
2	2	2	2	0.5	0.5
2	2	3	1	0.5	0.5
2	2	3	2	0.5	0.5

(c) Hierarchy level 3

Ac	P(Rc=2)	P(Rc=1)	P(Vs=2)	P(Vs=1)	P(Vn=4)	P(Vn=3)	P(Vn=2)	P(Vn=1)	P(Vsz=3)	P(Vsz=2)	P(Vsz=1)
1	0.5	0.5	0.5	0.5	0.25	0.25	0.25	0.25	0.3	0.3	0.3
2	0.5	0.5	0.5	0.5	0.25	0.25	0.25	0.25	0.3	0.3	0.3

Table 11.4: Hierarchical Initial Probability Distributions of Parameters

(a) Hierarchy level 4

Rc	P(En=2)	P(En=1)	Vs	Vn	Vsz	P(Pd=4)	P(Pd=3)	P(Pd=2)	P(Pd=1)	P(L=4)	P(L=3)	P(L=2)	P(L=1)
1	0.5	0.5	1	1	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
2	0.5	0.5	1	1	2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			1	1	3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			1	2	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			1	2	2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			1	2	3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			1	3	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			1	3	2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			1	3	3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			1	4	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			1	4	2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			1	4	3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			2	1	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			2	1	2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			2	1	3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			2	2	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
			2	2	2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
2	2	3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25			
2	3	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25			
2	3	2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25			
2	3	3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25			
2	4	1	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25			
2	4	2	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25			
2	4	3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25			

Table 11.5: Hierarchical Initial Probability Distributions of Parameters

(a) Hierarchy level 5

En	P(Os=4)	P(Os=3)	P(Os=2)	P(Os=1)
1	0.25	0.25	0.25	0.25
2	0.25	0.25	0.25	0.25

(b) Hierarchy level 6

Os	Pd	L	P(Acl=4)	P(Acl=3)	P(Acl=2)	P(Acl=1)	Os	Pd	L	P(Acl=4)	P(Acl=3)	P(Acl=2)	P(Acl=1)
1	1	1	0.25	0.25	0.25	0.25	3	1	1	0.25	0.25	0.25	0.25
1	1	2	0.25	0.25	0.25	0.25	3	1	2	0.25	0.25	0.25	0.25
1	1	3	0.25	0.25	0.25	0.25	3	1	3	0.25	0.25	0.25	0.25
1	1	4	0.25	0.25	0.25	0.25	3	1	4	0.25	0.25	0.25	0.25
1	2	1	0.25	0.25	0.25	0.25	3	2	1	0.25	0.25	0.25	0.25
1	2	2	0.25	0.25	0.25	0.25	3	2	2	0.25	0.25	0.25	0.25
1	2	3	0.25	0.25	0.25	0.25	3	2	3	0.25	0.25	0.25	0.25
1	2	4	0.25	0.25	0.25	0.25	3	2	4	0.25	0.25	0.25	0.25
1	3	1	0.25	0.25	0.25	0.25	3	3	1	0.25	0.25	0.25	0.25
1	3	2	0.25	0.25	0.25	0.25	3	3	2	0.25	0.25	0.25	0.25
1	3	3	0.25	0.25	0.25	0.25	3	3	3	0.25	0.25	0.25	0.25
1	3	4	0.25	0.25	0.25	0.25	3	3	4	0.25	0.25	0.25	0.25
1	4	1	0.25	0.25	0.25	0.25	3	4	1	0.25	0.25	0.25	0.25
1	4	2	0.25	0.25	0.25	0.25	3	4	2	0.25	0.25	0.25	0.25
1	4	3	0.25	0.25	0.25	0.25	3	4	3	0.25	0.25	0.25	0.25
1	4	4	0.25	0.25	0.25	0.25	3	4	4	0.25	0.25	0.25	0.25
2	1	1	0.25	0.25	0.25	0.25	4	1	1	0.25	0.25	0.25	0.25
2	1	2	0.25	0.25	0.25	0.25	4	1	2	0.25	0.25	0.25	0.25
2	1	3	0.25	0.25	0.25	0.25	4	1	3	0.25	0.25	0.25	0.25
2	1	4	0.25	0.25	0.25	0.25	4	1	4	0.25	0.25	0.25	0.25
2	2	1	0.25	0.25	0.25	0.25	4	2	1	0.25	0.25	0.25	0.25
2	2	2	0.25	0.25	0.25	0.25	4	2	2	0.25	0.25	0.25	0.25
2	2	3	0.25	0.25	0.25	0.25	4	2	3	0.25	0.25	0.25	0.25
2	2	4	0.25	0.25	0.25	0.25	4	2	4	0.25	0.25	0.25	0.25
2	3	1	0.25	0.25	0.25	0.25	4	3	1	0.25	0.25	0.25	0.25
2	3	2	0.25	0.25	0.25	0.25	4	3	2	0.25	0.25	0.25	0.25
2	3	3	0.25	0.25	0.25	0.25	4	3	3	0.25	0.25	0.25	0.25
2	3	4	0.25	0.25	0.25	0.25	4	3	4	0.25	0.25	0.25	0.25
2	4	1	0.25	0.25	0.25	0.25	4	4	1	0.25	0.25	0.25	0.25
2	4	2	0.25	0.25	0.25	0.25	4	4	2	0.25	0.25	0.25	0.25
2	4	3	0.25	0.25	0.25	0.25	4	4	3	0.25	0.25	0.25	0.25
2	4	4	0.25	0.25	0.25	0.25	4	4	4	0.25	0.25	0.25	0.25

Table 11.6: Hierarchical Initial Probability Distributions of Parameters

(a) Hierarchy level 7

Acl	P(Qcl=4)	P(Qcl=3)	P(Qcl=2)	P(Qcl=1)
1	0.25	0.25	0.25	0.25
2	0.25	0.25	0.25	0.25
3	0.25	0.25	0.25	0.25
4	0.25	0.25	0.25	0.25

(b) Hierarchy level 8

Qcl	P(S=2)	P(S=1)
1	0.5	0.5
2	0.5	0.5
3	0.5	0.5
4	0.5	0.5

Chapter 12

Reliability Analysis

Travel time is a good indicator of the performance of a certain highway segment. However, it does not convey every aspect of the overall performance of the transportation system. Therefore, fundamental analysis on travel time data is needed where various performance measures can be obtained such as reliability. Reliability is a measure of the variability of traffic conditions on a given link. Travelers tend to give a higher value to consistency of travel times rather than the pure travel time data; predictability is what is desired. Put in other terms, reliability of the route is of a great importance when assessing the system. Therefore, additional analysis is required on travel times. Various analysis approaches have been conducted for this purpose. Most commonly used are the traditional statistical methods demonstrating variability. A vital question to ask is how adequate is this standard statistical quantity. Could various analysis of travel time data lead to “better” reliability measures? In this section, different reliability analysis methods are introduced and conducted based on travel time mean estimation, non-failure analysis, and information theory. Travel time data on the Interchange 15 in Las Vegas is analyzed using the standard statistical approach such as planning time and buffer index as well as the new measures proposed in this study for evaluation.

12.1 Introduction

Travel time is the time that takes users of the road system to commute from an origin to a certain destination. Considering a fixed length of a highway section, travel times directly reflect traffic conditions, such as congestion due to recurring or nonrecurring events. Traffic conditions caused by nonrecurring events are highly unpredictable causing unexpected delays which directly affect travel times. This uncertainty results in variable traffic conditions and measured by “travel time reliability”. The uncertainty associated with travel times is of a major importance to drivers; it is highly ranked among all influential factors of departure time choice of travelers (5). The inconsistency of travel times inflict a scheduling cost where commuters have to budget extra time when traveling a certain route (13). Therefore, travel time reliability is an imperative measure in transportation system management (36).

Travel time reliability can take various quantitative measures all of which differ to a certain degree in the information they contain when evaluating the reliability of a route. The appropriate measure ought to be chosen depends on the evaluation criteria. Most researchers

as well as transportation entities use standard statistical methods when defining reliability. In this section, in addition to the traditional reliability measures, travel time variance and confidence intervals, failure analysis approach is introduced. Moreover, information theory based approach is proposed which adds a new dimension to the meaning of reliability. The proposed reliability measures are applied on travel time data obtained from Dynamic Message Signs (DMS) on the Interchange 15 (I-15) in Las Vegas in order to demonstrate the differences and what each measure introduces. A literature survey of different travel time reliability approaches is introduced in Section 12.2. Six quantitative reliability measures are proposed in Section 12.3. In Section 12.4, travel time reliability on the I-15 in the Las Vegas area will be assessed based on Dynamic Message Signs (DMS) data using the proposed methods. Discussion and conclusions are in Sections 12.5 and 12.6, respectively.

12.2 Literature Survey

Bogers in (5) recognizes the various reliability measures that have been used and stresses that the reliability analysis method depends on the application. Nie and Fan (33) developed an adaptive routing strategy, named the stochastic on-time arrival (SOTA) algorithm, to target least-expected travel time as a mechanism to address the performance measure of reliability. Oh and Chung (36) study travel time variability using data from Orange County, California. They study travel time variability that they compute in terms of variance in terms of day-to-day variability, within-day variability, and spatial variability. They concluded that travel time is correlated with standard deviation. Chen et. al. (13) demonstrates the relationship between travel time and level of service. They show how the 90th percentile travel incorporates the mean and variability into a single measure, and also study how travel time information using ITS can reduce travel uncertainty.

The median of travel times as a measure of reliability is used in Lam's study (46) (5). Black (4) defines a travel time reliability ratio which gives an assessment of the extra time commuters must account for based on variance (5). Van Lint (29) defines skew as a measure of the asymmetry of the travel time distribution and claims its importance in travel time reliability. Cambridge Systematic (19) used planning time, planning time index, and buffer index to measure reliability and found that buffer and planning time indices are very useful statistical measures. Buffer index is defined as the extra time needed to accomplish a certain trip with respect to the mean travel time; where, planning time index is an indication of the deviation of the buffer size from the ideal travel time (19).

Evidently, travel time reliability can take various measures; the optimal reliability approach choice dictated by the examined aspect of the specific application. In this study, six different reliability approaches are used to analyze travel time data on the I-15 Las Vegas area. Classical method, variability based on normalized standard deviation, Analysis of Variance ANOVA, travel time mean estimation, reliability as a measure of non-failures, and information theory based approaches are used and results are compared.

12.3 Reliability Measures and Technical Methods

The term “reliability” suggests repeatability or dependability. For a random experiment this would mean that the results of an experiment are repeatable. In terms of travel-time, this would mean that if travel time is measured repeatedly on a section we get comparable values. In general, repeatability of travel time could be framed in terms of time-of-day, day of the week, etc. Thus, travel time reliability is determined by conducting analysis on data measured for a certain segment.

In this study five different approaches are used in obtaining various reliability measures:

- Classical Method: Planning Time, Planning Time Index, Buffer Index
- Variability, Based on Normalized Standard Deviation,
- Analysis of Variance ANOVA
- Travel Time Mean Estimation,
- Reliability as a Measure of Non-failures, and
- Information Theory Based Approach

12.3.1 Classical Method: Planning Time, Planning Time Index, Buffer Index

Traditionally, reliability is measured through calculating planning time (the buffer) and two indices planning time index and buffer index through analyzing the travel time frequency distribution. Planning time or the buffer is calculated as the 95th percentile of travel time as demonstrated in Equation 12.1. The planning time buffer indicates the extra time travelers should account for in order to guarantee on time arrival. Planning time index is the ratio of the planning time to the ideal travel time (free flow) which indicates how planning time compares to ideal travel time giving more information about how severe traffic conditions are were the cheer buffer size (pplanning time) indicates consistency of travel times. Buffer index is the ratio of the difference between planning time and average travel time to the average travel time as demonstrated in Equation 12.2.

$$\tau_{pi} = \tau_p / \tau_f \quad (12.1)$$

$$B_i = \frac{\tau_p - \tau_A}{\tau_A} \quad (12.2)$$

where

τ_p : planning time (the 95th percentile)

τ_{pi} : planning time index

τ_f : free flow travel time

τ_A : average travel time

B_i : buffer index

12.3.2 Variability, Based on Normalized Standard Deviation

For a given set of travel time data on a freeway section, statistical mean can be calculated by Equation 12.3; however, travel time mean is not sufficient since it does not convey any information about how volatile the travel times are on the studied highway segment. Therefore, calculations of the standard deviation given in Equation 12.5 are necessary in order to understand the distributive nature of travel times (52). Clearly, a lower standard deviation indicates a higher concentration of data about the mean illustrating closer values to the mean; thus a more reliable highway segment.

$$\bar{\tau} = \frac{\sum_{i=0}^n \tau_i}{N} \quad (12.3)$$

$$\sigma = \sqrt{\frac{\sum_{i=0}^n (\tau_i - \bar{\tau})^2}{N - 1}} \quad (12.4)$$

$$\sigma_n = \sigma / \bar{\tau} \quad (12.5)$$

where

- τ_n : travel time on a certain highway segment
- $\bar{\tau}$: Average travel time for the given data set
- σ : Standard deviation of travel times for the given data set
- N : Total number of data points in the data set
- σ_n : Normalized standard deviation

12.3.3 Analysis of Variance (ANOVA)

Using ANOVA, the mean of various data sets were compared for hypothesis testing. A null hypothesis is defined by determining a desired α value representing the variation between the groups tested. If the ratio of the variance among the samples means to the variance within the samples F is less than F critical value (F_α), then the null hypothesis (H_0) is accepted indicating that the variation in mean falls within the desired regions. Otherwise, the alternate hypothesis (H_1) is accepted indicating higher variability thereof lower reliability.

$$\begin{aligned} H_0 : F &\leq F_\alpha \\ H_1 : F &> F_\alpha \end{aligned} \quad (12.6)$$

where:

- H_0 : Null hypothesis
- H_1 : Alternative hypothesis

12.3.4 Travel Time Mean Estimation Using t Statistics

Average of measured travel times of the sample data $\bar{\tau}$ may or may not reflect an accurate measure of the actual population mean μ (absolutely every travel time that existed). The actual travel time mean can be estimated using T distribution (since actual population variance is unknown) with a certain confidence interval 12.7. Travel time mean estimation with the specified confidence intervals delivers a practical measure that could be easily understood by the general public. Furthermore, this measure can be used for the day to day operations of emergency responders in the private and public sectors as well as general drivers. An automated statistical technique can be developed to reflect travel times given certain settings such as day, time, and location based on real time data.

$$1 - \alpha = 90\%$$

$$t = \frac{\bar{\tau} - \mu}{\sigma / \sqrt{n}} \quad (12.7)$$

The 90th percentile:

$$\Pr(\bar{\tau} - t_{\alpha/2} \frac{\sigma}{\sqrt{n}} < \mu < \bar{\tau} + t_{\alpha/2} \frac{\sigma}{\sqrt{n}}) = 0.9$$

where

$\bar{\tau}$: Average travel time for the given data set

σ : Standard deviation of travel times for the given data set

12.3.5 Reliability as a Measure of Non-Failures

One can perceive travel time reliability, R, as the probability of success of a certain route. This method provides probability of the extremes, pass or fail, defined in Equation 12.9. Success can take various meanings; in terms of travel time. Success of a highway segment can be defined as whether the actual travel time is below or above a desired travel time τ_d defined in Equation 12.8. This measure is a representation of the percentage of time a certain link is at a desired condition for instance free flow. It is easily understood by the general public and could be expanded further to measure reliability of complex networks. This measure is different from the traditional reliability meaning in that it indicates the success of the transportation system of maintaining travel times at free flow. This measure is more useful for transportation engineers, and policy makers.

$$\tau_d = \tau_{ff} + \tau_{th} \quad (12.8)$$

$$R_i = \frac{S_T}{N} \quad (12.9)$$

where

τ_d : Desired Travel Time
 τ_{ff} : Free Flow Travel Time
 τ_{th} : Travel Time Threshold, ex: 5 min
 N : Sample size
 S_T : Total number of successes, where $\tau < \tau_d$

Using this method, reliability of a highway segment R_s that consists of multiple contiguous segments $R_1, R_2 \dots R_n$ is determined as implied by Equation 12.10 (21)

$$R_s = \prod_{i=1}^n R_i \quad (12.10)$$

12.3.6 Information Theory Based Approach

In information theory, the information content, $H(n)$, contained in a certain message is given by Equation 13.1 (40)

$$\begin{aligned}
 H(n) &= \sum_{i=1}^n -P_i \log_2 P_i \\
 P_i &= n_i / n \\
 n &= \sum_{i=1}^k n_i
 \end{aligned} \quad (12.11)$$

where

$H(n)$: Information Content
 n : Total number of various travel times
 n_i : Frequency of travel times that lie within a specified interval

In terms of travel times, high information content indicates high variability on the considered segment of the highway. Therefore, an inverse relation of the information content is an appropriate measure of reliability. Such relation is given by Equation 13.2. This measure can also be expanded to represent a transportation network.

$$R = 1 / H(x) \quad (12.12)$$

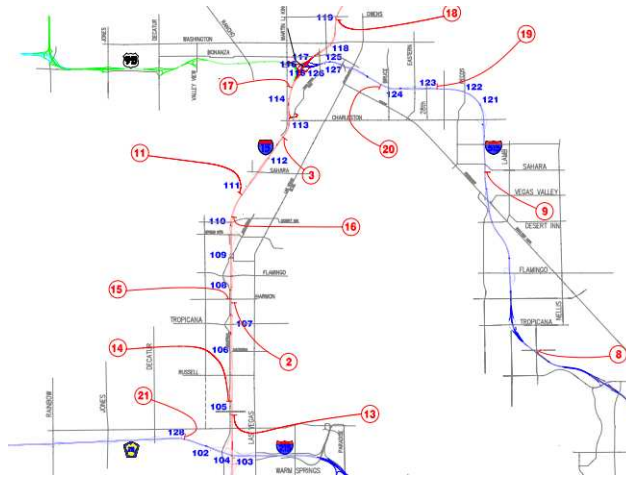


Figure 12.1: DMS on the I-15 corridor in Las Vegas from FAST

12.4 Travel Times and Reliability on the I-15 Las Vegas

12.4.1 Dynamic Message Signs

In order to demonstrate the proposed reliability measures, travel time data was obtained from The Freeway Arterial System of Transportation (FAST), an integrated Intelligent Transportation System organization in the Las Vegas area. FAST has approximately 21 Dynamic Message Signs (DMS) mostly distributed along the I-15 as depicted in Figure 13.5. Travel times are computed through the Incident Processing Module (IPM) in the Freeway Management System (FMS) where it processes detector data from traffic detector stations on the freeways; then, displayed on the DMS (26) (25).

The travel time data obtained spanned a period of eight months October 2008 through May 2009. Sign identifiers 13 and 17 were selected for analysis since they are located in main thoroughfares that are frequently traversed. Sign identifier 17 is located on the southbound I-15 freeway and it records the travel time from US-95 to the I-215. Sign identifier 13 is located on the northbound I-15 and it records the travel time from I-215 to US-95. The stretch of freeway covered by the chosen signs witnesses a high percentage of commuters daily which emphasizes the importance of studying it.

12.4.2 Data Processing

Initially, the dynamic message sign data received is a compilation of the date, time, location of the sign identifiers, the end destination, and the time traveled between segments along the I-15. The data record is in comma separated value format where each line of data is text.

Processing of the data is necessary to filter out some of the extraneous information in the data record and also to reorganize the important elements such as the date, time, travel time, the sign identifier, and end destination. For the filtering process and data recognition, code

was written in visual basic for applications (VBA) to automate the process in excel. The program separates the data into new sheets by the sign identifier and end destination. Within each of these sheets, the data is organized by date and quarter hour. For each quarter hour, the average is computed. Using a pivot table with the day and end destination assigned to the row field ,the hour and quarter hour assigned to the column field, and the average travel time assigned to the data field, the data is reorganized into a new table where the averages are computed for each hour while still displaying the quarter hour averages.

By providing estimated travel times with a high degree of reliability, drivers will be able to plan their trips with greater ease and accuracy. After the data is processed, averages are computed for two hour intervals and for days of the week. Averaging the data for every two hour interval, allowed for analysis of consistency of travel time between different periods of the day. Averaging the data for days of the week, allows for analysis on a broader scope. Moreover, the consistency of the travel time and the day to day variability can be assessed.

12.5 Results and Discussion

Two types of analysis were conducted, day-to-day and within the day reliability, on the DMS data obtained from FAST using the six proposed methods.

12.5.1 Variability, Based on Normalized Standard Deviation (NSTD)

Tables 12.1(a) and 12.1(b) list the obtained NSTD for both signs.

Table 12.1: Normalized Standard Deviation

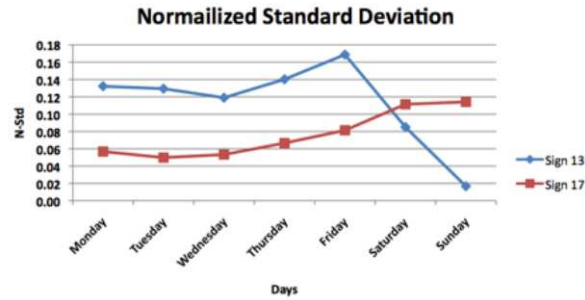
(a) Day to day

Std. Statistics:	Sign 13				Sign 17			
	Average	Variance	Std	N-Std	Average	Variance	Std	N-Std
Monday	13.37	3.12	1.77	0.13	13.86	0.62	0.79	0.06
Tuesday	14.43	3.48	1.87	0.13	13.10	0.42	0.65	0.05
Wednesday	14.97	3.17	1.78	0.12	13.57	0.52	0.72	0.05
Thursday	14.44	4.09	2.02	0.14	12.52	0.69	0.83	0.07
Friday	14.88	6.30	2.51	0.17	14.14	1.32	1.15	0.08
Saturday	11.32	0.92	0.96	0.08	9.67	1.16	1.08	0.11
Sunday	10.30	0.03	0.17	0.02	9.25	1.11	1.05	0.11

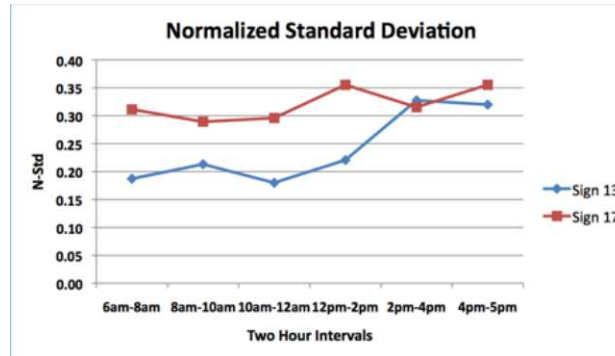
(b) Within the day

Std. Statistics	Sign 13				Sign 17			
	Average	Variance	Std	N-Std	Average	Variance	Std	N-Std
6am-8am	12.84	5.78	2.40	0.19	12.36	14.81	3.85	0.31
8am-10am	13.69	8.51	2.92	0.21	12.29	12.62	3.55	0.29
10am-12am	12.97	5.45	2.33	0.18	12.26	13.15	3.63	0.30
12pm-2pm	15.02	10.99	3.31	0.22	14.54	26.69	5.17	0.36
2pm-4pm	22.97	56.59	7.52	0.33	17.00	28.71	5.36	0.32
4pm-5pm	22.07	49.84	7.06	0.32	17.82	40.12	6.33	0.36

Figures 12.2(a) and 12.2(b) show the normalized standard deviation trends for signs 13 and 17.



(a) Day to Day



(b) Within the Day

Figure 12.2: Normalized Standard Deviation Analysis

The data was processed in two different ways day to day and within the day. Day to day processing aggregates travel times for a one day at a time which allows comparison of aggregated travel times between different days of the week as well as weekends.

Examining the obtained results for day to day analysis for sign 13 (north bound direction of the I15), higher variability is noted during week days. Yet, lower overall NTSD was obtained for sign 17 (I-15 south bound) compared to sign 13. However, results of the processed data during weekends show a higher variability for I-15 south bound (sign 17) than I-15 North bound (sign 13). This phenomenon may be caused by the fact that drivers' destination for that section of the freeway is most likely to be in the south direction during weekends since it leads to the center of the town. Overall reliability is not very high which means that traffic conditions on that segment are somewhat inconsistent.

From analyzing the obtained values of the normalized standard deviation for within the day processing, it is noted that the values are higher than the values obtained for day to day analysis. This was expected since traffic conditions vary tremendously from throughout the day taking into consideration traffic demand during peak hours as well as off peak hours; however, aggregating the values to represent a day as whole will result in a more consistent travel times. Less consistency is noted when travel times are compared for all days vs. when only alike days are compared. This emphasizes the importance of data processing methods and how different processing can give different meanings. Overall, higher reliability is noted on I-15 North which is inconsistent with day to day analysis.

The same data will be analyzed in the subsections to follow using the various proposed methods in order to extract the information that each one provides.

12.5.2 Analysis of Variance ANOVA

Tables 12.2(a), 12.2(b), 12.2(c), and 12.2(d) show the F value obtained from the ANOVA hypothesis test with $\alpha = 0.05$. The F values obtained from ANOVA analysis for both signs and the two types of analysis (day to day and within the day) are greater than the critical value F_α which indicates rejection of the null hypothesis. These results show low consistency in travel times for the studied freeway section; thus, low reliability.

Table 12.2: Analysis of Variance (ANOVA)

(a) Sign 13, Day to day

Sign 13		
F	P -value	F crit
253.1153	2.6E-125	2.123994

(b) Sign 17, Day to day

Sign 17		
F	P -value	F crit
59.5566	6.95E-51	2.123994

(c) Sign 13, within the Day

ANOVA		
F	P -value	F crit
193.1984	1.8E-151	2.221484

(d) Sign 17, within the day

ANOVA		
F	P -value	F crit
56.4523	7.88E-53	2.221521

12.5.3 Travel Time Mean Estimation

Tables 12.3(a) and 12.3(b) illustrate the average travel time with 95 percent confidence. Depicted in Figures 12.3(a) and 12.3(b) the 95th percentile for both signs.

As expected, the 95 th percentile averages approximately 18 and 14 minutes for sign 13 and 17, respectively during week days; however, it is much lower on weekends. Analyzing within the day values, it is noticeable that travel times are much higher in the afternoon than it is in the mornings as shown in Figures 12.3(a) and 12.3(b).

12.5.4 Reliability as a Measure of Non-failures

Tables 12.4(a), 12.4(b), 12.4(c), and 12.4(d) show the results obtained when non-failure analysis is used in determining reliability. Figures 12.4(b) and 12.4(a) illustrate the trend for both day to day and within the day.

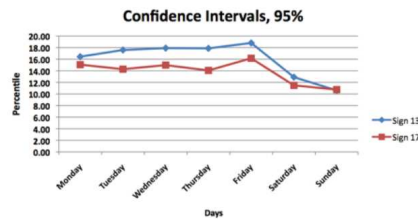
Table 12.3: Average travel time estimation with 95% confidence

(a) Day to day

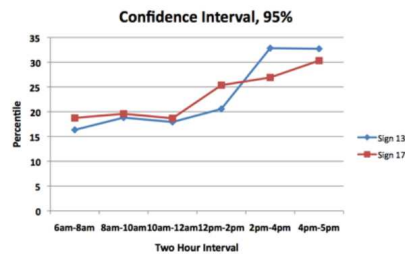
Confidence Intervals:	Sign 13		Sign 17	
	Time	Percentile	Time	Percentile
Monday	12.96 < t < 13.78	16.44	13.68 < t < 14.04	15.06
Tuesday	13.99 < t < 14.86	17.59	12.95 < t < 13.26	14.28
Wednesday	14.55 < t < 15.38	17.92	13.41 < t < 13.74	14.98
Thursday	13.97 < t < 14.91	17.87	12.32 < t < 12.71	14.06
Friday	14.29 < t < 15.46	18.81	13.87 < t < 14.41	16.16
Saturday	11.09 < t < 11.54	12.91	9.42 < t < 9.92	11.48
Sunday	10.26 < t < 10.34	10.62	9.00 < t < 9.49	10.76

(b) Within the day

Confidence Intervals:	Sign 13		Sign 17	
	Times	Percentile	Time	Percentile
6am-8am	12.56 < t < 13.12	16.35	11.92 < t < 12.81	18.75
8am-10am	13.35 < t < 14.02	18.82	11.87 < t < 12.70	19.59
10am-12am	12.70 < t < 13.24	17.93	11.84 < t < 12.68	18.68
12pm-2pm	14.64 < t < 15.41	20.57	13.94 < t < 15.14	25.37
2pm-4pm	22.10 < t < 23.84	32.84	16.38 < t < 17.62	26.92
4pm-5pm	21.25 < t < 22.89	32.71	17.09 < t < 18.56	30.32



(a) Day to Day



(b) Within the Day

Figure 12.3: The 95th percentile

Data was compared to an eleven minute threshold based on a free flow speed of 65 mph as well as segment length which is approximately 10.5 and 7.7 miles for signs 13 and 14, respectively. The results show a higher overall reliability for sign 17 (south bound) than it is for sign 13 (north bound). The studied freeway section is unreliable in the afternoon as well as weekends for both directions. In this case reliability indicates whether travel times are above or below the desired travel time.

Table 12.4: Reliability as a measure of non-failure analysis

(a) Sign 13, Day to day

Failure Analysis:	Sign 13						
	Min	Max	Range	Threshold	Success	Failure	R
Monday	10.58	16.51	5.94	11	3	49	0.058
Tuesday	10.94	17.68	6.74		1	51	0.019
Wednesday	11.72	17.99	6.27		0	52	0
Thursday	10.71	17.93	7.22		3	49	0.058
Friday	10.67	18.85	8.18		3	49	0.058
Saturday	10.33	12.94	2.61		25	27	0.481
Sunday	10.07	10.62	0.55		52	0	1

(b) Sign 17, Day to day

Failure Analysis:	Sign 17						
	Min	Max	Range	Threshold	Success	Failure	R
Monday	11.83	15.10	3.27	11	0	52	0
Tuesday	11.59	14.31	2.72		0	52	0
Wednesday	12.34	15.02	2.67		0	52	0
Thursday	10.73	14.09	3.36		2	50	0.038
Friday	12.48	16.18	3.71		0	52	0
Saturday	8.26	11.59	3.33		43	9	0.827
Sunday	8.19	10.77	2.57		52	0	1

(c) Sign 13, within the Day

Failure Analysis	Min	Max	Range	Threshold	Success	Failure	R
6am-8am	9.00	31.10	22.10	11	52.0	151	0.256
8am-10am	9.63	22.94	13.31		48.0	155	0.236
10am-12am	9.63	24.29	14.67		32.0	171	0.158
12pm-2pm	9.83	30.67	20.83		20.0	183	0.099
2pm-4pm	9.63	38.85	29.23		14.0	189	0.069
4pm-5pm	10.17	42.40	32.23		3.0	200	0.015

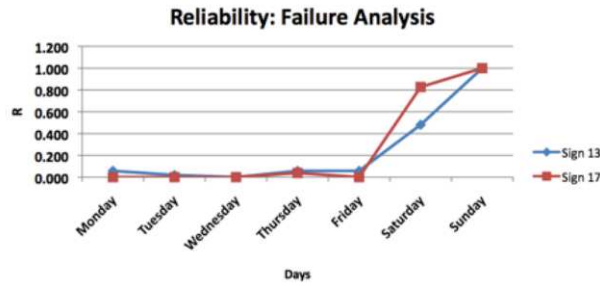
(d) Sign 17, within the day

Failure Analysis	Min	Max	Range	Threshold	Success	Failure	R
6am-8am	7.63	30.98	23.35	11	97	105	0.480
8am-10am	7.63	24.73	17.10		94	108	0.465
10am-12am	7.63	25.71	18.08		94	108	0.465
12pm-2pm	8.60	33.42	24.81		65	137	0.322
2pm-4pm	8.63	37.23	28.60		21	181	0.104
4pm-5pm	8.08	32.81	24.73		27	175	0.134

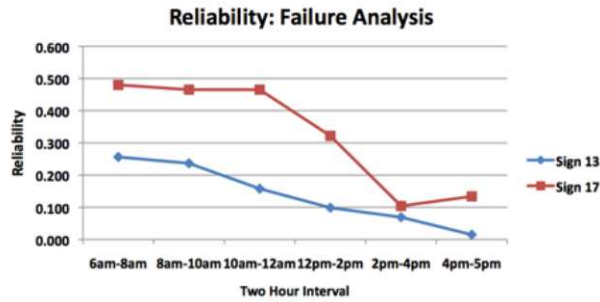
12.5.5 Information Theory Based Approach

The reliability values obtained by using information theory are presented in Tables 12.5(a) and 12.5(b). The trends of the reliability are depicted in Figures 12.5(a) and 12.5(b)

Conducting the analysis using information theory, results have demonstrated consistency with the values obtained for NSTD showing higher reliability thereby lower variability for sign 17 (south bound) compared to sign 13 (north bound) during week days. A reversed effect is seen when day is analyzed within the day.



(a) Day to Day



(b) Within the Day

Figure 12.4: Reliability as non-failure Analysis

Table 12.5: Information Theory Based Reliability

(a) Day to day

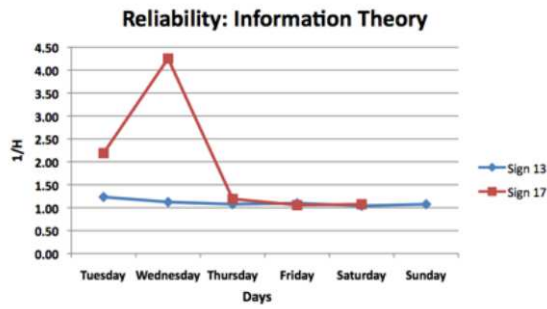
	Sign 13	Sign 17
Information Theory Analysis:	1/H	1/H
Monday	1.23	2.19
Tuesday	1.12	-
Wednesday	1.07	4.25
Thursday	1.10	-
Friday	1.04	1.19
Saturday	-	1.06
Sunday	1.07	1.07

(b) Within the day

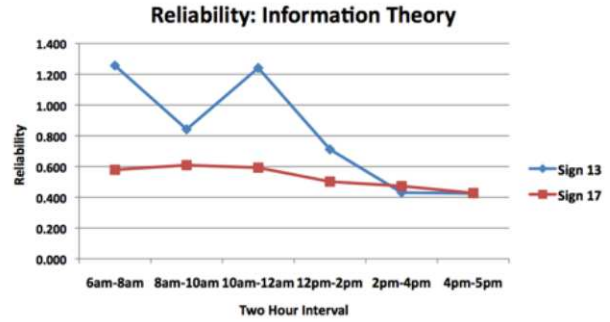
	Sign 13	Sign 17
Information Theory Analysis:	1/H	1/H
6am-8am	1.256	0.579
8am-10am	0.842	0.609
10am-12am	1.240	0.592
12pm-2pm	0.711	0.501
2pm-4pm	0.431	0.473
4pm-5pm	0.425	0.427

12.6 Conclusions

In this study five reliability approaches were introduced, variability based on normalized standard deviation, analysis of Variance ANOVA, travel time mean estimation, reliability as



(a) Day to Day



(b) Within the Day

Figure 12.5: Information theory based reliability

a measure of non-failures, and information theory based approach. These methods were applied to the I-15 corridor in Las Vegas. Traditional reliability measures were solely based on consistency. However, it does not address the issue of whether the travel time is acceptable or not regardless of its consistency. Put in other terms, consistency of travel times does not necessarily indicate desired travel times. Therefore, reliability measure based on non-failures considers various thresholds when determining reliability. It was also demonstrated that reliability could be obtained based on information theory which analyzes the frequency of data belonging to certain intervals.

Chapter 13

Performance Measures

Reliability is an extremely important measure for every industry, starting from small devices to large systems like transportation networks. Reliability definitions are inconsistent among the different industries and strongly based on the application and the nature of the system. In manufacturing, reliability theory has been well established for many years, and significant developments have been made. Many reliability measures for transportation systems have been developed as well; however, many of these measures are up for debate by raising a number of questions. In particular, how representative are these developed measures of the transportation system's performance? Furthermore, many researchers have observed inconsistencies among these measures which results in confusion among transportation engineer and policy makers. Researchers argue that the definition of "reliability" and how to measure reliability in transportation is subject to debate. In this research, the transportation system is broken down into its essential components. The definition of "reliability" and the measurement of each component is studied. Finally, how to use reliability measures to assess the performance of the transportation system as a whole is addressed.

13.1 Introduction

The reliability of transportation systems has been mainly focussed on consistency of travel times of a certain trip or route. "Travel time" is the time that takes users of the road system to commute from an origin to a certain destination. Considering a fixed length of a highway section, travel times directly reflect traffic conditions, such as congestion due to recurring or nonrecurring events. Traffic conditions caused by nonrecurring events are highly unpredictable, causing unexpected delays that directly affect travel times. This uncertainty results in variable traffic conditions and is measured by "travel time reliability." The uncertainty associated with travel times is of a major importance to drivers: in fact, it is highly ranked among all influential factors of departure time choice of travelers (5). The inconsistency of travel times inflict a scheduling cost, where commuters have to budget extra time when traveling a certain route (13). Also, manufacturing operations give travel time reliability more importance than delayed trips (48). Therefore, travel time reliability is an imperative measure in transportation system management (36). Lomax (48) recognizes some of the possible sources for inconsistency, such as incidents, work zones, weather, fluctuations in demand, special events, traffic control, and inadequate capacity. He also argues that reliability measures should indicate how much each source contributes to the inconsistency, when

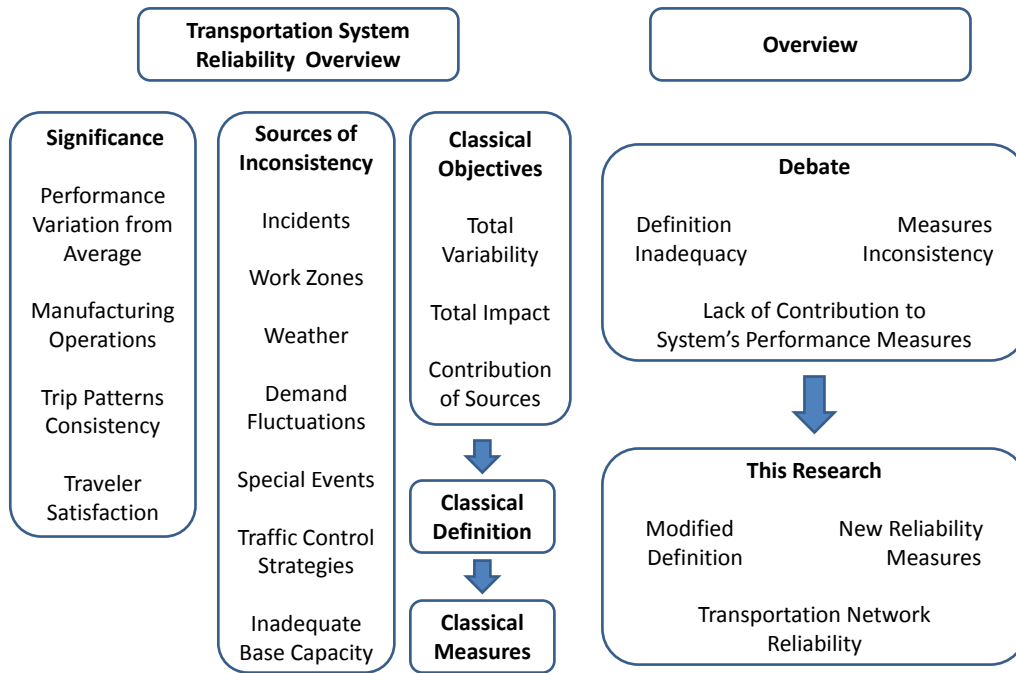


Figure 13.1: Transportation system reliability and section overview

possible, this is highly dependent on the measure used as well as on the available data.

Travel time reliability can be evaluated using various quantitative measures, all of which differ to a certain degree in the information they contain. The appropriate measure that ought to be chosen depends on the evaluation criteria. Most researchers as well as transportation entities use standard statistical methods when defining reliability.

Bogers (5) recognizes the various reliability measures that have been used and stresses that the reliability analysis method depends on the application. Nie and Fan (33) developed an adaptive routing strategy, named the stochastic on-time arrival (SOTA) algorithm, to target least-expected travel time as a mechanism to address the performance measure of reliability. Oh and Chung (36) studied travel time variability by using data from Orange County, California. They studied travel time variability that was computed in terms of day-to-day variability, within-day variability, and spatial variability. They concluded that travel time is correlated with standard deviation. Chen et. al. (13) demonstrated the relationship between travel time and level of service. They show how the 90th percentile travel incorporates the mean and variability into a single measure; they also studied how travel time information using ITS can reduce travel uncertainty.

The median of travel times as a measure of reliability was used in Lam's study (46) (5). Black (4) defines a travel time reliability ratio that gives an assessment of the extra that commuters must account for, based on variance (5). Van Lint (29) defined "skew" as a measure of the asymmetry of the travel time distribution, and claimed that skew was important in travel time reliability. Cambridge Systematic (19) used planning time, planning time index, and buffer index to measure reliability; they found that buffer and planning time indices are very

useful statistical measures. The buffer index is defined as the extra time needed to accomplish a certain trip with respect to the mean travel time, where planning time index is an indication of the deviation of the buffer size from the ideal travel time (19).

Overall transportation reliability research has come to agree on the importance of measuring inconsistency of travel times for certain trips as well as inconsistency of performance. Many reliability measures were developed and shown to be “good measures”. However, as stated in Lint’s work (20), all these measures have been proven to be inconsistent with each other: they do not accurately measure inconsistency and, as a whole, are inadequate measures for the performance of the transportation network. As illustrated in Figure 13.1, this study presents a discussion of the classical definition for reliability, and measures for reliability in section 13.2. Proposed new approaches targeting the issues raised in the discussion are presented in section 13.3. Conclusions and recommendations are in section 13.4.

13.2 Discussion of Classical Reliability Approach

13.2.1 Classical Reliability Definition

Lomax (48) recognizes that the common definition for reliability used in transportation to be the level of consistency in travel times. In this context, reliability allows assessment of the performance of certain elements of transportation systems such as a mode, trip, route, or a corridor.

13.2.2 Classical Reliability Measures

Classical reliability measure can be categorized into four classes as depicted in Figure 13.2: statistical range, buffer time, tardy trip, and probabilistic. Clearly, the main focus of these measures are travel time reliability.

Statistical range relies on expected value (average travel time) as well as standard deviation calculations upon which the following measures are based: travel time window, percent variation, and variability index. The travel time window indicated the expected travel time range that is experienced by travelers. Percent variation is the percentage of variation in travel time with respect to average travel time. The variability index is the percentage of the range of travel time and indicated the inconsistency level during peak hours with respect to off peak hours.

Buffer time measures are also based on average travel time. Furthermore, this class of measures uses percentiles (defined as planning time) and ideal travel times in their calculations. They indicate the extra amount of time that the traveler must allow to reach the desired destination at the desired time. The most common set of measures that are based in buffer time are buffer time, buffer time index and planning time. Basically, buffer time is the difference between the expected travel time and the 95th percentile travel time. In other words, it is the

Class	Measures	Formula	Description	
Statistical Range	Travel Time Window	$TTW = TT_{Avg} \pm \sigma$	The expected travel time range experienced by travelers.	
	Percent Variation	$PV = \frac{\sigma}{TT_{Avg}} \times 100\%$	The percentage of variation in travel time with respect to average travel time.	
	Variability Index	$V_i = \frac{(U_{95\%} - L_{95\%})_{Peak}}{(U_{95\%} - L_{95\%})_{Off-Peak}}$	The percentage of travel time range (inconsistency level) during peak hours with respect to off peak hours.	
Buffer Time	Buffer Time	$BT = PT - TT_{Avg}$	The difference between the expected travel time and the 95 th percentile travel time (the extra travel time cause by variability)	
	Buffer Time Index	$BT_i = \frac{BT}{TT_{Avg}}$	The percentage of buffer time with respect to the expected travel time	
	Planning Time Index	$PT_i = PT/TT_{id}$	The percentage of the planning time (95 th percentile) with respect to the ideal travel time	
Tardy Trip	Florida Reliability Method	$FR = (1 - \frac{n_{TR > TR_{th}}}{N_{tr}}) \times 100\%$	The percentage of trips where travel times are less or equal to expected travel time.	
	On Time Arrival	$OTA = (1 - \frac{n_{TR > 110\%TR_{th}}}{N_{tr}}) \times 100\%$	The percentage of time where travel times are less or equal to expected travel time.	
	Misery Index	$M_i = \frac{TR_{Avg(10\%to20\%trips)} - TR_{Avg}}{TR_{Avg}}$	The ratio of the difference between the average travel rate for the longest 20% of total trips and average travel rate of total trips.	
Probabilistic	Travel Time Unreliability	$P(TT \geq \alpha \cdot TT_{th})$	The probability that the travel time is larger than a certain threshold recognized as the upper limit for success.	
Acronyms	TT – TravelTime Avg – Average σ – StandardDeviation	U – Upper L – Lower Id – Ideal	PT – PlanningTime(95 th Percentile) n_{tr} – NumberOfTrips N_{tr} – TotalNumberOfTrips	TR – TravelRate TT_{th} – TravelTimeThreshold

Figure 13.2: Classical reliability measures summary

extra travel time caused by variability. The buffer time index is the percentage of buffer time with respect to the expected travel time. The planning time index is the percentage of the planning time with respect to the ideal travel time.

Tardy Trips is a class of measures that indicate how often travelers are late. This measure is based on thresholds that are preset in order to define what is considered to be late; in the previous measure, buffer time, calculations are mostly based on averages. Tardy trips measures are also based on the extra delay incurred during the worst trips (20). Florida reliability, on time arrival, and misery index are examples of reliability measures of this class. The Florida reliability method gives the percentage of trips where the travel times are less than or equal to the expected travel time. “On time arrival” indicates the percentage of time where travel times are less than or equal to the expected travel time. The ratio of the difference between the average travel time rate for the longest 20% of total trips and average travel rate of total trips is given by misery index.

Probabilistic measures are based on distribution fitting of the random variable. The transportation component’s reliability to be measured becomes the random variable for which the appropriate distribution is determined, based on the nature of the component. This measure indicates the probability of success based on a threshold set by the evaluator, for instance, the probability that the travel time is greater than a certain threshold. The distribution that is used can vary based on what is being measured. For instance, the following are common distributions used for extreme event failure such as incidents and failure of traffic control devices: gamma, Weibull, normal, exponential, log normal, Poisson process, and

truncated normal. This area must be further studied for transportation systems; however, it is not the main concern of this section.

13.2.3 Issues with Classical Reliability Definition and Measures

By carefully examining the classical reliability measures, one can obtain far more information from the values other than pure inconsistency. For instance, the tardy trip and the probabilistic class of measures deliver reliability with respect to a certain threshold that determines the success rate and/or the failure rate. Even though this meaning of “reliability” is not touched upon by the classical definition, it is of major interest to researchers as well as to transportation systems evaluators. It is also a vital indicator of the system’s performance.

Inadequacy of the measures is another issue with the classical reliability measure. Lint (20) highlighted that classical measures are highly inconsistent in providing conclusions regarding the reliability of a certain trip or roadway segment. This is a predictable result since all of these measures use various thresholds. Another flaw in using these measures is that most of them assume a symmetrical distribution in calculating the variability ranges; this is inaccurate, particularly because symmetrical distributions are not the most appropriate for extreme event analysis. Therefore, a measure of inconsistency needs to be developed irrespective of any threshold or distribution.

The lack of equipment in order to measure network reliability is another issue. Lint argues that these measures are inadequate in terms of cost for evaluating the performance of the system. Such evaluation is crucial for policy makers and the optimization of budget allocation in transportation projects. In order for a certain value to serve as a good performance measure, it must capture such information as the safety of the link, emissions, and incident rates. Thus, the development of network reliability measures is highly necessary.

Issues with the classical reliability definition and measures can be summarized as follows:

1. Definition Inadequacy
2. Inconsistency Extraction
3. Network Reliability

13.3 New Reliability Approach

As illustrated in Figure 13.3, this section introduces possible approaches in targeting the reliability issues that have been raised. Reliability definitions from the manufacturing field are discussed and introduced to the transportation world. Information theory approach is used to address measuring inconsistency adequately. Reliability of the transportation system as a network is also addressed.

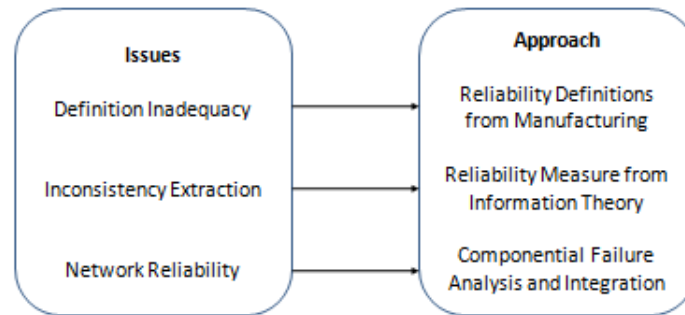


Figure 13.3: Classical reliability issues and corresponding new approaches

13.3.1 Reliability Definition from Manufacturing

In manufacturing, reliability has been well developed both theoretically as well as practically. Even though at first glance the reliability of electronic or mechanical systems seems to be much different than it is for transportation systems, conceptually, there is a common interest for the “system” regardless of its nature to work “properly” or as expected. As indicated in Section 13.2, the classical definition of transportation reliability does not capture all reliability aspects that can be captured by the developed measures.

The following are various reliability definitions have been collected from the book Mathematical Theory of Reliability by Barlow (3) and Probability Models by Ross (45):

1. “Reliability is the probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered”(45).
2. “Point-wise availability: The probability that the system will be able to operate within the tolerances at a given instant of time”(45).
3. “Interval availability: The expected fraction of a given interval of time that the system will be able to operate within the tolerances”(45).
4. “Limiting interval availability” is the expected fraction of time in the long run that the system operates satisfactorily(45).
5. “Interval reliability is the probability that at a specified time, the system is operating and will continue to operate for an interval of duration, say x ”(45).
6. “Reliability theory is concerned with determining the probability that a system, possibly consisting of many components, will function”(45).

The plots in Figure 13.4 describe the listed reliability definitions.

In the classical definition of reliability in the transportation field, the concepts of probability of failure or success as well as interval and point availability are not covered. The probability of success, for instance, is what is being measured by the probabilistic class of measures. Therefore, it is proposed that the classical definition of reliability be modified to include the availability for a given time. When it comes to transportation, it is of interest to measure reliability of both a certain trip as well as the performance of the transportation network as a

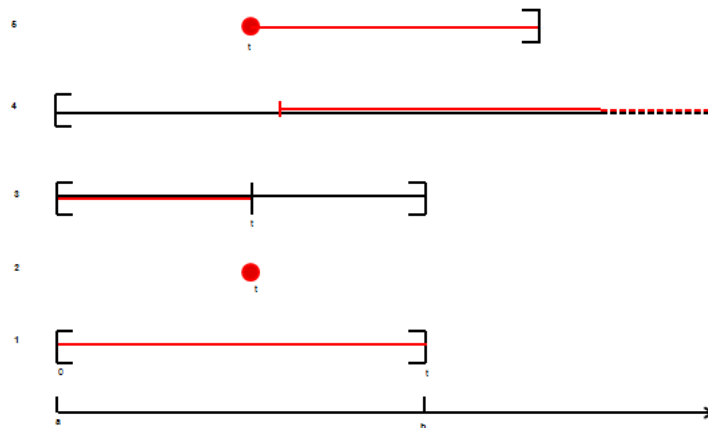


Figure 13.4: Description of reliability definitions

whole. Reliability of a trip should measure consistency as well as availability. Even though consistency of travel times were determined to be the most significant, it is evident that a more meaningful measure must contribute to the system's performance evaluation. In this case, this would indicate congestion levels in terms of "point-wise-availability," or the probability that the travel time of a route is within a desired threshold. However, when measuring reliability of a transportation system as a complete network composed of various components, averaging travel times over the whole network becomes unusable. One can obtain an overall indicative measure of the system's performance by adequately obtaining the reliability of its components. This measure must indicate the effectiveness of the interaction among the components and the dependence on reliability.

Proposed definitions :

Reliability of a trip or a route is the probability that the travel time for a specific trip is within the tolerances at a given instant of time and is consistent with respect to a given time range.

Reliability of the transportation system as a complete network composed of various components is given by the probability that the system will function within the desired thresholds at a given point of time.

13.3.2 Reliability Measure Based on Information Theory

It is agreed upon that consistency of travel times is one of the most important reliability measure. As illustrated in Section 13.2, classical reliability measures do not adequately measure consistency of travel times. In this section, a new approach for measuring consistency, inspired by information theory, is introduced. Information theory measures the informational content in a certain message or data set, in which a high value indicates that highly variable information is contained in the data and a low value indicates very low informational content in the data. It is proposed in this section the information theory measures be applied to travel time data in order to extract pure consistency, irrespective of the traffic conditions.

In information theory, the information content, $H(n)$ contained in a certain message is given by Equation 13.1 (40)

$$H(n) = \sum_{i=1}^n -P_i \log_2 P_i$$

$$P_i = n_i/n$$

$$n = \sum_{i=1}^k n_i$$
(13.1)

where

$H(n)$: Information Content

n : Total number of various travel times

n_i : Frequency of travel times that lie within a specified interval

In terms of travel times, high information content indicates high variability on the considered segment of the highway. Therefore, an inverse relation of the information content is an appropriate measure of reliability. Such a relation is given by Equation 13.2. This measure can also be expanded to represent a transportation network.

$$R = 1/H(x)$$
(13.2)

Sample Data Analysis Comparison Using Information Theory and Normalized Standard Deviation

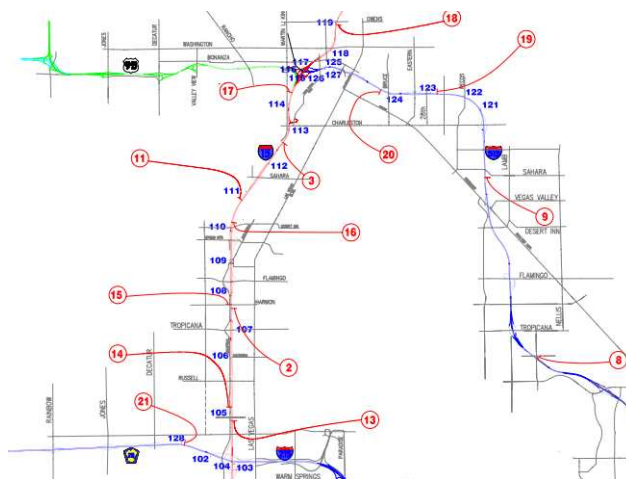


Figure 13.5: DMS on the I-15 corridor in Las Vegas from FAST

In order to demonstrate the proposed reliability measure, travel time data was obtained from The Freeway Arterial System of Transportation (FAST), an integrated Intelligent Transportation System organization in the Las Vegas area. FAST has approximately 21 Dynamic Message Signs (DMS) mostly distributed along the I-15 as depicted in Figure 13.5. Travel times are

computed by means of the Incident Processing Module (IPM) in the Freeway Management System (FMS). The detector data from traffic detector stations on the freeways is processed and then displayed on the DMS (26) (25). The travel time data that was obtained spanned a period of eight months October 2008 through May 2009. Sign identifiers 13 and 17 were selected for analysis since they are located on main thoroughfares that are frequently traversed. Sign identifier 17, located on the southbound I-15 freeway and it records the travel time from US-95 to the I-215. Sign identifier 13, located on the northbound I-15, records the travel time from I-215 to US-95. The stretch of freeway covered by the chosen signs witnesses a high percentage of commuters daily, which emphasizes the importance of studying it.

Table 13.1: Sample data analysis using normalized standard deviation and information theory method

WTD	Sign 13		Sign 17	
	NSTD	R=1/H	NSTD	R=1/H
6am-8am	0.187163	1.2557	0.311352	0.578616
8am-10am	0.213138	0.841594	0.289197	0.608803
10am-12pm	0.179985	1.24048	0.295932	0.592126
12pm-2pm	0.220637	0.711041	0.355287	0.501438
2pm-4pm	0.327517	0.430565	0.315249	0.472603
4pm-5pm	0.319869	0.424599	0.355392	0.427308

Since classical measures are strongly based on standard deviation calculations, reliability calculations for the obtained data was performed using the new proposed information theory measures and the classical normalized standard deviation method. Results are compared, as shown in Table 13.1 and presented in Figures 13.6.

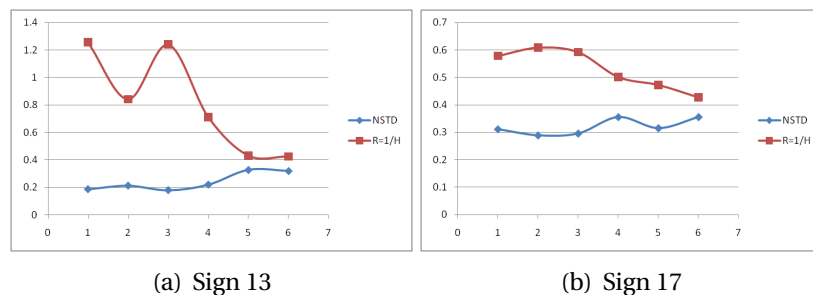


Figure 13.6: Within the day analysis using Normalized standard deviation and the new information theory measure based approach

From Figures 13.6(a) and 13.6(b), it is clear that the two measures, normalized standard deviation (NSTD) and information theory based measure (ITM), give consistent results. High NSTD indicates high inconsistency, whereas high ITM indicates high consistency; therefore, a symmetrical pattern is viewed in the plots. It is also shown that an approach based on information theory is far more sensitive to variations in travel times since it does not take into consideration the expected values or any other threshold. Instead, it measures pure inconsistency of data, which is exactly what is needed.

13.3.3 Network Reliability

Transportation systems are composed of many components that are highly networked. Components of the transportation system can be chosen based on the criteria of the system's per-

formance evaluation. For instance, a transportation system can be viewed as a network of the most common trip routes. One can also view the transportation system as a network of the seven inconsistency sources mentioned in the introduction (incidents, work zones, weather, fluctuations in demand, special events, traffic control, and inadequate capacity). Either case, a proper reliability measure must be developed for each component. Once developed, a Network Structure Map (NSM) can be developed based on the network's actual topology, with which the overall reliability of the transportation system can be measured. It is evident that the operation of some components is essential for the operation of other components. Therefore, components of the transportation network may have two possible connections: a series connection or a parallel connection. Two components are connected in series if the operation of one depends on the operation of the other; parallel connections take place when the operation of one component is totally independent of the operation of the other one. Network Structure Functions (NSF) and NSM are depicted and illustrated in Figure 13.7 (45).

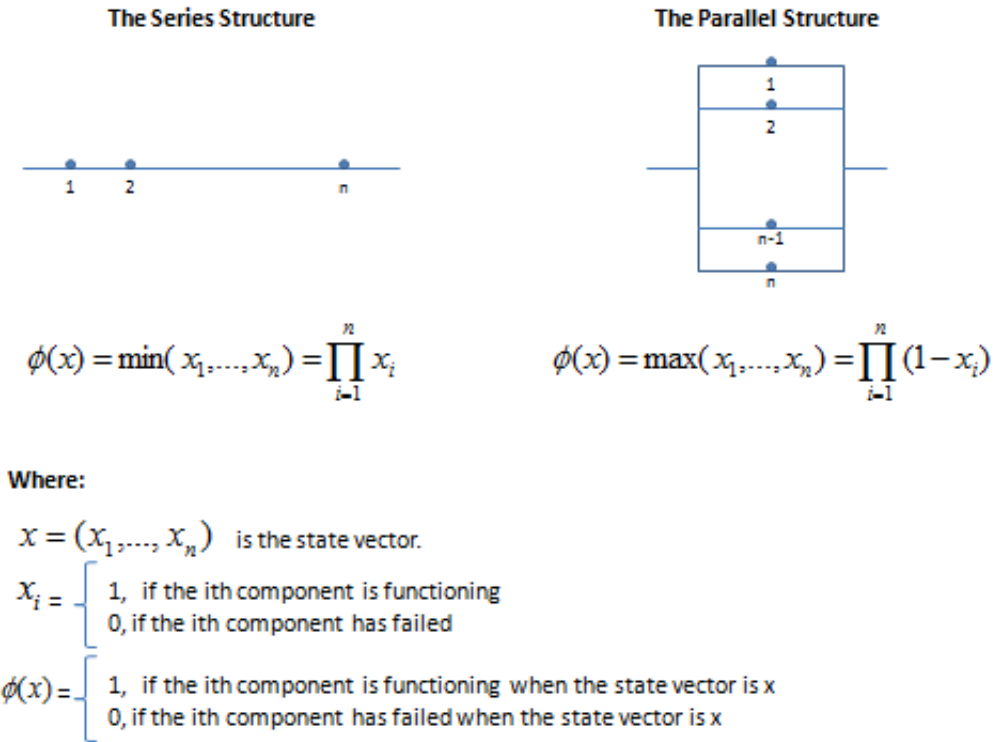


Figure 13.7: Network Reliability

13.4 Conclusions

Classical reliability definition and measures were studied and discussed in this section. The classical definition was not consistent with the developed measures. Also, classical reliability measures are not consistent with each other, do not well represent consistency, and do not address the overall performance measure of the transportation system. These three issues

where targeted in this study. In addition, a modified definition inspired by manufacturing was introduced. A reliability measure based on information theory was introduced and was shown to measure inconsistency more accurately than standard deviation. Finally, a network reliability measure was introduced. In future work, a more aggressive data analysis will be conducted to demonstrate the proposed methods.

Part V

Appendix

Appendix A

After Survey

General

1. What is your agency?
2. What is your job title?
3. How long is your experience in the field?
 - (a) 2 years or less
 - (b) Between 2 and 5 years
 - (c) Between 5 and 10 years
 - (d) More than 10 years
4. Select all that falls under your agency's jurisdiction
 - (a) North Las Vegas
 - (b) Northwest Las Vegas
 - (c) Southwest Las Vegas
 - (d) South Las Vegas
 - (e) East Las Vegas
 - (f) Henderson
 - (g) Clark County
 - (h) Freeway
 - (i) I-15
 - (j) US-95
 - (k) I-215 CC-215
 - (l) Arterial roads, State roads (McCarran Blvd, etc.)
 - (m) On-ramps
 - (n) Off-ramps

(o) Other:

5. In what type of incidents does your agency get involved (select all that apply)?

- (a) Single Vehicle Crash
- (b) Disabled/Abandoned vehicle
- (c) Multi-Vehicle crash
- (d) Hazardous material spill
- (e) Debris on Roadway
- (f) Weather related debris on roadway
- (g) Other:

6. At what phase of the Traffic Incident Management (TIM) does your agency get involved? (select all that apply)

- (a) Incident Detection
- (b) Incident Verification
- (c) Incident Response
- (d) Incident Site Management
- (e) Traffic Management
- (f) Incident Clearance
- (g) Incident First Responder (medical)
- (h) Recovery
- (i) HazMat or Large Vehicle Spill Containment
- (j) Other:

7. How do you first get to know about an incident?

- (a) Phone call from travelers to 911 that is forwarded to your agency
- (b) Phone call from other agencies (i.e., DPS-NHP, NDOT, please indicate the agency name below)
- (c) Radio (please indicate below if by public radio or emergency i.e., 150Mhz, 700Mhz, or 800Mhz system)
- (d) Drive by observation of the incident
- (e) Other:

Policies

Use the following rating scale to give a rating in the table below on how you think each policy influences the IM response. Complete the table below using one of the following options in the second column (Rate 1-6):

1. This policy will dramatically improve Incident Management (IM)

2. This policy will slightly improve IM
3. This policy will not affect IM
4. This policy will worsen IM
5. This policy is impossible to implement
6. I do not know

Questions:

1. Rate each policy 1-6
2. Are you aware of this policy? Yes/ No
3. Do you already practice this policy? Yes/ No
4. What additional Policies could improve the Traffic Incident Management process?
5. What do you think could improve/enhance your agency response and clearance times?

Policy	Q1	Q2	Q3
Policy 1: REGIONAL OPEN ROADS POLICY: Safely clear highway incidents within 30 minutes for non injury accidents, 60 minutes for injury accidents and 90 minutes for fatality crash scenes, spill/contaminants and "big rig" overturns.			
Policy 2: PERFORMANCE MEASUREMENT GOALS / POLICY: First Responder agencies will cooperate to identify ways to measure response times for each agency and roadway clearance times for each incident.			
Policy 3: INCIDENT RESPONSE VEHICLE (IRV) POLICY: Traffic incidents involving multiple vehicles, fatalities, "big rig" overturn or contaminant/spills, shall have an incident response vehicle (IRV) dispatched to manage traffic and assist Incident Command at the scene with quick and decisive clearing of the highway.			
Policy 4: TIM LIGHTING POLICY: Reducing the number of emergency lights at secured incident scenes. Forward lighting should be limited to travel to/from a major incident and special consideration should be given to extinguishing all forward facing flashing or wig-wag emergency lights, especially on divided highways. Once adequate traffic control has been established and orange cones have been placed to assure a lane of safety, amber lights are recommended for use by all TIM responder agencies at the scene of an incident (i.e. fire, law enforcement, NDOT, Towing, etc).			
Policy 5: APPARATUS PLACEMENT AND SCENE PROTECTION POLICY: When possible, lane blocking should be limited to initiating one additional lane of barrier protection for the safety of first responders serving a scene.			
Policy 6: MULTI-DISCIPLINARY TIM PLANNING AND TRAINING POLICY: All first responder agencies located in the TIM boundaries shall promote cooperation, coordination, communication and consensus building that support the regional Open Road Partnership Agreement dated October 28, 2008. TIM members will develop a regional approach to TIM planning, training and policies for the Las Vegas region.			
Policy 7: TIM FATALITY INVESTIGATION POLICY: In the event of a fatality or major traffic incident, whenever possible, the investigative technology used should include photogrammetry to allow 3D reconstruction of the incident away from the incident scene where the first responder is safe.			
Policy 8: REMOVAL OF DECEDENTS AT FATALITY ACCIDENTS IN THE TIM BOUNDARIES: NHP will notify the County Coroner within 15 minutes of identifying that there has been a traffic incident with a fatality. It shall then be the policy of the Clark County Office of the Coroner/Medical Examiner (CCOCME) to appropriately investigate and remove victims of fatality accidents from the Traffic Incident Management (TIM) corridor in the most expeditious manner possible. The CCOCME may choose to allow other first responder authority to remove the victim from the place the body has landed or allow the body to be removed with the "jaws of life" before investigation has been completed as long as digital photographs have been taken for later investigations.			
Policy 9: COMMUNICATIONS POLICY: Traffic incident responders will work together through the TIM Coalition to develop and implement standardized multi-agency, multi-disciplinary traffic incident communications practices and procedures among ALL first responders. Including, but not limited to, face-to-face communications in the regional traffic management center (NHP-FAST Center), remote voice radios (whenever available), electronic text, use of CCTV cameras and any means available in order to insure prompt, seamless response to traffic incidents.			
Policy 10: FAST TMC TIM SURVEILLANCE AND TRAVELER INFORMATION POLICY: The FAST TMC provides CCTV camera surveillance and Dynamic Message Sign (DMS) availability for transportation and emergency management personnel 24/7. It is the regional policy of the TIM Coalition that all appropriate first responder agencies may have access to CCTV cameras available to them for verification of traffic incident severity and committing assets to respond (Las Vegas Metropolitan Police Department, Clark County Fire Department, etc.).			
Policy 11: WRECKER OPERATOR AND TRUCK REQUIREMENT POLICY: Towing operators will have operator training and TIM approved driver certification for towing all classes of vehicles. NHP will keep a list of approved towing companies. NHP dispatch will notify the towing company of the class of vehicle they will be towing according to the TRAA Vehicle Identification Guide. Towing companies will respond within 30 minutes of notification to appear at the scene. A company with 2 missed calls in one month will be considered for a 30 day suspension. Tow companies are required to clear all travel lanes within 60 minutes once they have been given the "go ahead" by the Incident Command officer on scene.			
Policy 12: SPILLS/CONTAMINATES REMOVAL POLICY: NDOT shall provide for state of Nevada highways, and, Clark County will provide for Clark County highways, services for the primary purpose of clearing spills/contaminates and overturned big rigs from the mainline thoroughfares as quickly as possible, thus allowing unimpeded and continued traffic flow.			
Policy 13: UNIFIED COMMAND FOR TRAFFIC INCIDENT MANAGEMENT: Police is the primary emergency response incident command agency for traffic incidents on the highway. The fire department is the primary emergency response incident command agency for fire suppression, hazardous materials spills, rescue and extrication of trapped crash victims. In the event of a fatality, overturned "big rig", Contaminant/spill or major traffic incident that will take 60 minutes or longer to clear, Unified Command System will be used for the TIM region; stressing a partnership. The first responder to arrive on the scene will be responsible for forming a unified command structure upon arrival of other first responders. Input is encouraged from all agencies represented at the scene to develop a well coordinated management strategy for clearing the scene as safely and efficiently as possible.			
Policy 14: MULTI-AGENCY, MULTI-DISCIPLINARY TIM PLANS FOR CONSTRUCTION: Highway construction projects required to prepare a TIM Plan under MUTCD Guidelines, will be presented by the sponsoring agency representative, preferably the Project Manager, during the design phase of the project in order to engage the TIM members responsible for maintenance, enforcement and operations of the corridor being considered for construction.			
Policy 15: TIM AFTER ACTION REVIEW DEBRIEFING POLICY: Any incident taking longer than 90 minutes to clear from the roadways will "trigger a debriefing of that traffic incident" at the next regularly scheduled TIM Coalition meeting. The purpose of the debriefing is to determine what - if anything - could have been done differently to achieve the 90 minute regional clearance goals. The After Incident Review Procedures will be adhered to for scheduling and conducting the debriefing. All agencies who participated in the original traffic incident will participate in this valuable process.			

Communications

1. This communication is usually required at this stage:
 - (a) Incident Detection,
 - (b) Verification,
 - (c) Response,
 - (d) Site management,
 - (e) Traffic management,
 - (f) Incident clearance,
 - (g) Recovery
2. The following communication method is used for this purpose: (i.e. phone, Public radio, emergency radio system, cell phone, etc.)
3. This communications is needed:
 - (a) 0-20%,
 - (b) 21- 40%,
 - (c) 41-60%,
 - (d) 61- 80%, or
 - (e) 81-100% of the time
4. This communications is successful:
 - (a) 0-20%,
 - (b) 21- 40%,
 - (c) 41-60%,
 - (d) 61- 80%, or
 - (e) 81-100% of the time
5. A successful communications takes about this many minutes on average
6. Ideally, this action should not take more than this many minutes
7. Could this communication be improved (Yes, No), and how?

Communications among agencies

Agency	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
PD								
PW								
Fire								
Traffic								
FAST								
CC Maint.& Op.								
CC Coroner								
RFC								
NPS								
NHP								
LVMPD								
FSP								
Towing								
ESR (PC)								
Other								

Communications within the same agency

Please answer the same questions as above. In addition, please specify what entity from within your agency in the first column under “Entity”.

Entity	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8

Data Collection

Questions

1. What is the data collected at your agency of which you are aware? (check all that applies):
2. Do you collect data about other agencies as well?
 - (a) 1- yes, which agency
 - (b) 2-No
3. Rate how challenging it is to collect the mentioned data: (rate from 1-5. 1-being the most difficult and, 5- being the easiest)
4. What format is the data in? Give a list of formats

5. Is the data easily accessible? (rate from 1-5. 1-being the most difficult and, 5- being the easiest)
6. Would a hand held device that allows entering data in an efficient and easy fashion be helpful?
- (a) Yes
 - (b) No
 - (c) We already have such a system

Data	Q1	Q2	Q3	Q4	Q5
Time call received					
Time Unit dispatched					
Time unit on the way to scene					
Time unit arrived to scene					
Time unit finished tasks required at the scene					
Time at which the unit leaves the scene					
Traffic conditions					
Timestamp					
Lane closure					
Number of vehicles involved					
Number of passengers for each vehicle					
Type of vehicle					
belted or not					
weather conditions					

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