FREEWAY INCIDENT DETECTION AND ARTERIAL SYSTEMS MANAGEMENT FOR THE I-84 CORRIDOR PHASE I

Interim Report

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Background

Freeway incident management has become an important issue in departments of transportation nationwide. While incidents on freeways cannot be prevented entirely, the implementation of an effective incident detection and management system can mitigate the impacts of the resultant congestion.

It has long been known that the weakest elements of incident management programs are the Automated Incident Detection (AID) algorithms and the incident recovery phase, particularly the utilization of traffic diversion strategies. An Incident Management Plan (IMP) was recently developed for Idaho's Treasure Valley corridor, which identified possible diversion routes and established incident response plans for a wide range of scenarios. The Treasure Valley includes the cities of Boise, Garden City, Meridian, Eagle, Kuna, Star, Middleton, Nampa, and Caldwell in Ada and Canyon counties. To maximize the benefit of these diversion routes, effective signal control and management strategies need to be devised that use the actuated controllers already deployed in the I-84 corridor.

Project Objectives

NIATT will:

1) Test and evaluate a minimum of six of the standard incident detection algorithms that are commonly used today and help to determine which ones may be suitable for use in the I-84 corridor.
2) Develop and test signal control strategies that can be used in conjunction with the I-84 diversion route plans to improve traffic flow on parallel arterials during incident situations.

3) Develop a set of materials based on the simulation models developed for this study that can be used to train practicing professionals and university engineering students to operate a freeway traffic management center.

Accomplishments of Phase I of this Project

The duration of this project is 24 months, divided into two 12-month phases. This report describes the accomplishments of Phase I:

- The software was developed for analyzing the I-84 freeway data and testing the AID algorithms.
- Freeway data were collected and used to analyze the freeway operation and incident characteristics for the corridor. The results show that the freeway corridor operates under stable free-flow conditions with volume/capacity ratios ranging from 0.42 to 0.72.
- Six algorithms were evaluated and tested using the Treasure Valley freeway data, and the output from these algorithms is presented in this report.
- Three simulation models for the Treasure Valley corridor were developed, calibrated and validated. A preliminary analysis of the Treasure Valley IMP was conducted using these models. The results of the analysis show that the reduction in the area-wide delay as a result of implementing the freeway diversion route plans can range from 13.9% to 27.2%.

Proposed Phase II Activities

- The parameter values of the six algorithms will be further examined and a new set of values will be developed and tested. After the parameter values are adjusted to reflect site-specific characteristics, recommendations can be made for the use of a particular algorithm in the I-84 corridor.
- Signal control plans will be developed and tested for the actuated controllers located on the arterial system networks in the proposed diversion route plans.
- A set of materials and facilities will be developed that can be used to train practicing professionals and students in managing freeway incidents and TMC operations.

1. INTRODUCTION

1.1 Background

Freeway incident management has become an important issue in departments of transportation nationwide. With many of the nation's roadways operating very close to capacity under the best of conditions, the need to reduce the impact of incident-related congestion has become critical. Non-recurring congestion caused by random events such as accidents, spilled loads, disabled vehicles or any other special event, represents up to 60% of the overall congestion on urban freeways, which can result in significant costs. While incidents on freeways cannot be prevented entirely, the implementation of an effective incident detection and management system can mitigate the impacts of the resultant congestion.

1.2 The Process of Incident Management

The process of managing an incident has four distinct stages: detection, response, clearance, and, with full capacity restored, recovery. Figure 1 graphically represents incident-based delay with and without an incident management system.

In general, the impact of incidents on traffic flow can be minimized by implementing incident management programs that:

- Reduce the time to detect and verify the incident.
- Reduce the response time for personnel and equipment to arrive at the incident location.
- Effectively manage on-site personnel, equipment and traffic.
- Implement effective diversion route plans to reduce incident-based delay.
- Reduce the time to clear the incidents.
- Provide timely and accurate information to motorists, including possible diversion routes.

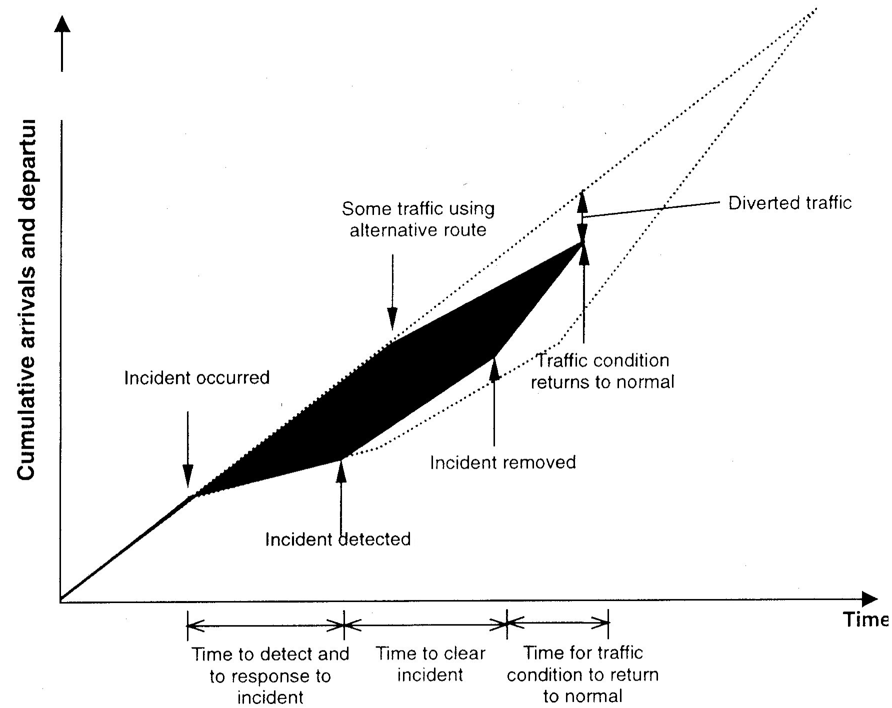

Figure 1. Incident-Based Delay With and Without an Incident Management System

1.3 Current Idaho Projects

In an effort to improve travel conditions in Idaho's Treasure Valley Corridor, the Idaho Transportation Department (ITD) has collaborated with other transportation agencies in the Treasure Valley area to plan a series of projects related to the application of Intelligent Transportation Systems (ITS). These projects are part of the ITS Integration Program funded by the Federal ITS Deployment Plan. Three such projects are the design, construction and implementation of a Traffic Management Center (TMC) for the Treasure Valley, the development of an Incident Management Plan (IMP) that encompasses the freeway and the arterial systems, and the design and implementation of ITS devices on I-84.

1.3.1 Treasure Valley Traffic Management Center (TMC)

The Treasure Valley includes the cities of Boise, Garden City, Meridian, Eagle, Kuna, Star, Middleton, Nampa, and Caldwell in Ada and Canyon counties (Figure 2). As part of the ITS deployment plan in the Treasure Valley area, the Ada County Highway District (ACHD) completed work on a state-of-the-art TMC in January of 2000.

The TMC controls 240 of ACHD's 328 traffic signals, along with managing the operation of most of the arterial streets and the freeways (I-84 and I-184) within the Treasure Valley that are under ITD's jurisdiction.

This unique joint operation between ACHD and ITD facilitates integrated freeway and arterial system management, and hence more efficient traffic operation is possible. This will be particularly valuable during incident situations, as some of the freeway traffic can be diverted onto the arterial system network. The TMC also operates strategically located Changeable Message Signs (CMS) when necessary, and uses closed circuit TV camera (CCTV) systems to provide surveillance. Figure 2 illustrates the locations of the ITS components within the Treasure Valley area.

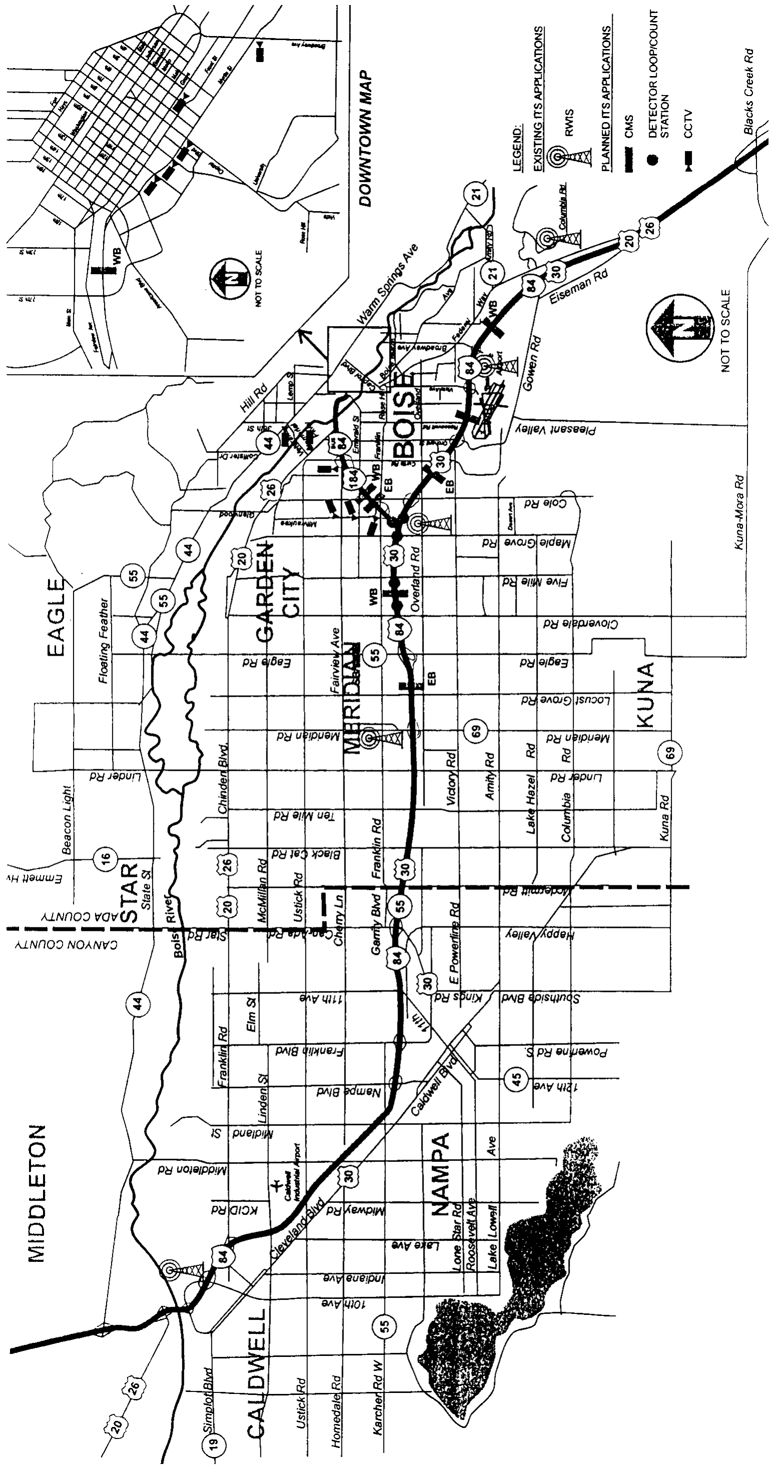

Figure 2. Treasure Valley ITS Components and their Deployment Locations

Source: Treasure Valley ITS-Freeway Management Master Plan, Meyer, Mohaddes Associates, Inc. (1999)

1.3.2 Development of an Incident Management Plan (IMP)

An IMP has been developed for the Treasure Valley that coordinates the incident management efforts among the transportation agencies in the area. The incident management plan provides scripted instructions for incident site management, re-routing of traffic along alternative routes and protocols that the TMC operator should follow. The plan provides a comprehensive checklist of steps that should be taken by all the response agencies to most effectively manage an incident, from detection through clearance and freeway flow restoration. System control software will be installed in the TMC that has the capability of controlling all of the system's components.

1.4 Problem Statement

Many incident management programs have been established in urban areas nationwide to help reduce the magnitude of incident-induced congestion. It has long been known that the weakest elements of these programs are the Automated Incident Detection (AID) algorithms and the incident recovery phase, particularly the utilization of traffic diversion strategies. Although diversion strategies are used in many areas, they have not been fully evaluated to determine their impact on the local transportation system. In most cases, in fact, only the impact on the freeway has been considered. Further, diversion is typically used only in extreme cases, but it might also be beneficial during incidents of moderate severity and duration. For example, the incident management handbook developed for the FHWA states, "In general, when two or more lanes of a freeway are expected to be shut down for two or more hours, institution of the alternate route plan should be considered."

If delay is to be minimized on a network as a whole, the incident management program will need to incorporate comprehensive traffic management strategies, and decision aids will need to be developed for defining recovery strategies. Careful analysis of diversion strategies including examination of the operational characteristics of the freeway and diversion routes can lead to far more efficient and effective incident management strategies.

1.5 Project Objectives

The purpose of this project is to enhance and build upon the work that was completed for the Treasure Valley IMP project by accomplishing some additional, and important, objectives:

1) A variety of AID algorithms are currently available, but most need calibration before they can be applied to a particular area. Each detection system varies in terms of detection rates, false alarm rates and times to detection. Off-line testing of the algorithms will be required before they can be implemented online in the system.

> **Project Objective One:** NIATT will test and evaluate six of the standard incident detection algorithms that are commonly used today and help to determine which ones may be suitable for use in the I-84 corridor.

2) Another important component of the freeway/arterial integrated management system is the effective operation of the signal systems on the parallel arterials where freeway traffic is being diverted. Freeway diversion plans were developed for the Treasure Valley corridor by Transcore and Six Mile Engineering. The study identified possible diversion routes and established incident response plans for a wide range of incident scenarios. To maximize the benefit provided by these diversion routes, effective signal control and management strategies can be devised for the actuated controllers in the I-84 corridor. Various congestion management schemes need to be evaluated, such as increasing cycle length and adding green time to the main street, measuring congestion, and testing other queue detection/control strategies.

> **Project Objective Two:** NIATT will develop and test signal control strategies that can be used in conjunction with the I-84 diversion route plans to improve traffic flow on parallel arterials for the I-84 corridor during freeway incidents.

3) The integrated freeway/arterial system simulation models for the Treasure Valley corridor will also be used to provide training for ITD personnel and TMC operators, as part of their preparation for detecting and managing incidents. The simulation models will allow them to test and evaluate incident response scenarios and diversion plans for a variety of incidents under different traffic flow conditions.

> **Project Objective Three:** NIATT will develop a set of materials based on the simulation models that can be used to train practicing professionals and university engineering students to operate a traffic management center.

1.6 Scope of Work

1) Collect information about AIDs currently in use.
2) Profile current freeway operational characteristics with and without incidents using ITD's Automatic Traffic Recorder (ATR) data.
3) Apply AIDs on the freeway data collected.
4) Develop CORSIM simulation models for the I-84 corridor network.
5) Test freeway diversion plans and arterial signal control strategies using the CORSIM simulation models.

   The simulation models developed for the Treasure Valley corridor are valuable tools for analyzing diversion strategies. The critical freeway volume at which diversion becomes advantageous can be determined, as can bottleneck locations on the alternate routes. Signal timing adjustments can be tested and fine-tuned to achieve the ideal maximum flow along the diversion route. The combined freeway/arterial roadway system was considered in the analysis so strategies that provide the lowest overall system-wide delay could be established rather than merely shifting the problem from one location to another.
6) Develop training materials that utilize the simulation models.

1.7 Accomplishments of Phase I of this Project

The duration of this project is 24 months, divided into two 12-month phases. This report describes the accomplishments of Phase I. Below is a brief description of these accomplishments. See Section 9 of this report for proposed Phase II activities.

During Phase I of the project, the following tasks were accomplished:

- The software was developed for analyzing the freeway data and testing AID algorithms.
- Freeway data were collected, and used to analyze the freeway operation and incident characteristics for the corridor.
- Six AID algorithms were evaluated and tested using the Treasure Valley freeway data.
- Three simulation models for the Treasure Valley corridor were developed, calibrated and validated.
- A preliminary analysis of the Treasure Valley IMP was conducted using these models.

1.8 Organization of the Report

This reports contains nine sections. Section One provides an introduction to the project and background information. Section Two presents current freeway traffic operational characteristics for the I-84 corridor. Section Three presents current incident characteristics for the I-84 corridor. Section Four presents a review of the implemented incident detection algorithms and Section Five presents the tested algorithms' output. Section Six presents the simulation models developed and Section Seven describes the results of the simulation model analysis. Section Eight includes a summary of the findings of the report. Section Nine presents proposed Phase II activities.

2. CURRENT FREEWAY OPERATIONAL CHARACTERISTICS FOR THE I-84 CORRIDOR

2.1 Freeway Data Collection and Management

Freeway traffic data were obtained from the ITD Division of Transportation Planning. ITD has embedded inductive loop sensors at fairly regular intervals along I-84 through Boise. The data from each detector station is collected and stored by a roadside Automatic Traffic Recorder (ATR). The ATR data is routinely downloaded and stored by a unit in the Division of Planning.

The ATR data is available in four formats. The format that was appropriate for our purposes is called the Individual Vehicle Records (IVR) format. IVRs provide speeds and length of vehicles by individual loops on a lane-by-lane basis. This is the most detailed level of data obtainable from the ATRs. From this level, data at any level of aggregation can be derived.

The ATRs located on I-84 within the Treasure Valley Corridor study area are listed in Table 1. The table also lists the type of data collected at each of these stations. As speed and occupancy measurements, which are typically used by incident detection algorithms, are the key factors in this study, stations that report volume only (West Nampa and Vista Rd.) were excluded from the data collection activities. However, some archived data for these stations were used to establish traffic flow profiles at these locations. IVR data were collected and maintained for the other seven stations (Robinson Rd., Five Mile Rd., Overland Rd, Orchard Rd., Broadway Ave., Jeans Place, and Blacks Creek). To account for the seasonal variation of traffic, the data collection covered the period from November 2000 through May 2001. In addition to the traffic data, weather condition data for the Boise area were collected through the national weather service center website.

Table 1. Automatic Traffic Recorders Located on I-84 within the Treasure Valley Corridor

Site Number	Location	Milepost	Data Type
094	West Nampa EB	32.4	Volume
	West Nampa WB	32.4	Volume
142	Robinson Rd. EB	39.7	Binned
	Robinson Rd. WB	39.7	Binned
121	Five Mile EB	47.93	Binned
122	Five Mile WB	47.93	Binned
260	Overland EB	49.73	Binned
263	Overland WB	49.73	Binned
261	Orchard EB	51.29	Binned
262	Orchard WB	51.29	Binned
263	Vista Rd. EB	53.1	Volume
264	Vista Rd. WB	53.1	Volume
265	Broadway EB	53.92	Binned
	Broadway WB	53.92	Binned
002	Jeans Place EB	58.73	Raw
	Jeans Place EB	58.73	Raw
87	Blacks Creek EB	62.1	Raw
	Blacks Creek WB	62.1	Raw

Figure 3 depicts the approximate locations of the detector stations in this segment of I-84 through the Boise urban area. The sets of three-digit numbers on either side of this schematic denote the ATR number. Some locations have the same number on both sides. For example, at Broadway the ATR number is 265 on both sides, while at Orchard the number in the Eastbound direction is 261, while in descending (or Westbound) direction it is 262. This means that at Broadway one ATR collects information for both directions of traffic, while at Orchard there is one for each direction. Loop sensors are installed at Vista, but they are not shown in this schematic because they are not “double-loop.” Two loops are needed for speed measurements, and since many of the proposed algorithms required speed information, the data from Vista was not applicable.

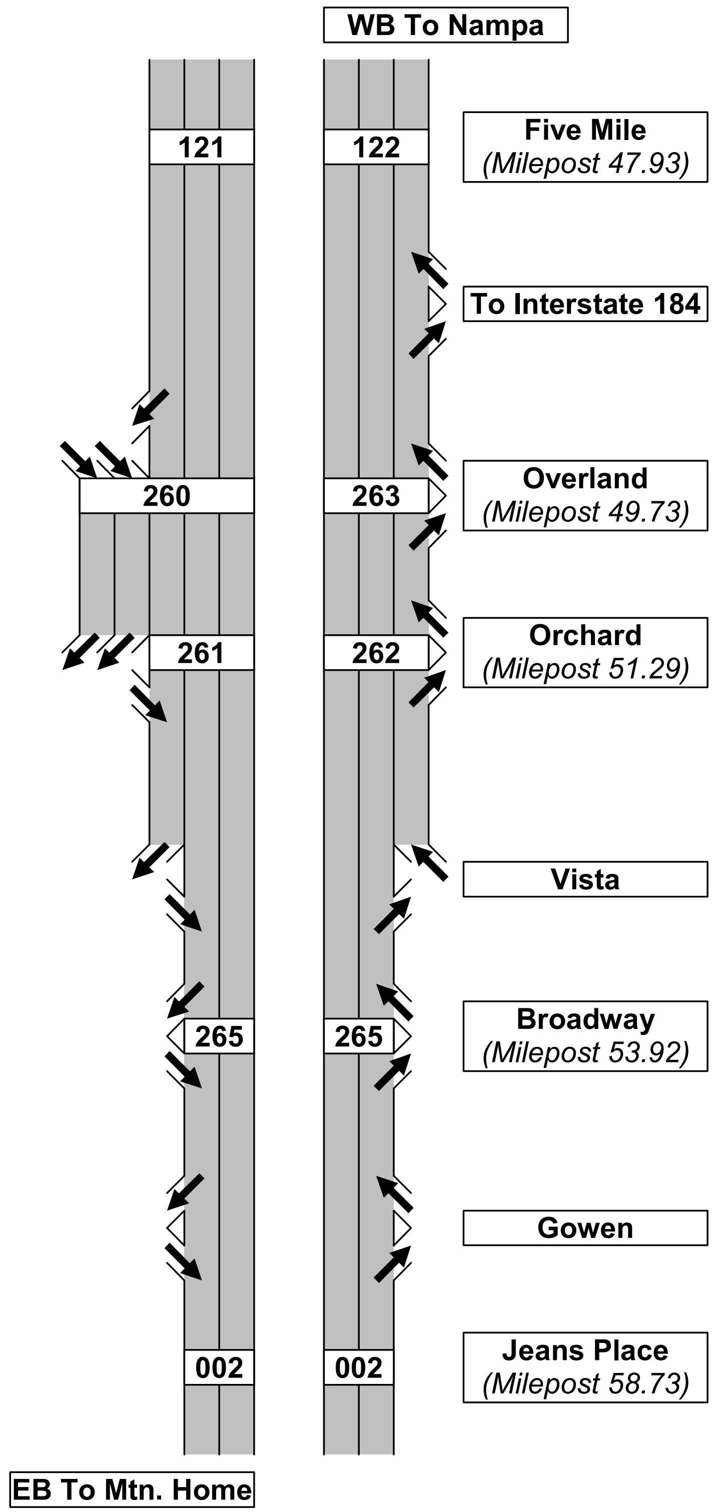

Figure 3. Detector Station Schematic

The first step in managing the freeway data was to transfer the raw (vehicle-by-vehicle) data to two Access databases. The first database included the vehicle-by-vehicle lane of travel, time, speed, and vehicle length data. The second database included the lane-by-lane volume, average speed, average detector occupancy aggregated over 30-second intervals, and weather condition (clear, rain, or snow). The files also included the volume, the weighted average speed, and the average occupancy for the lanes.

As the ATRs report speed and volume data only, the detector occupancy, used in many incident detection algorithms, was derived from the speed and volume data using the fundamental speed, flow, and density relationship: K=Q/V where K is the traffic density (vehicle per lane-mile), Q is the traffic flow (vehicle per hour), and V is the average speed (miles per hour). The percent occupancy was then obtained using the relationship:

$$\%OCC= \frac{1}{52.8} K(L_V + L_D) \text{ where:}$$

% OCC	is the % of time the detector is occupied during the time interval
K	is the traffic density (vehicle per lane-mile) during the time interval
L_v	is the average vehicle length during the time interval (feet)
L_D	is the detection zone length (feet)

2.1.1 Data Analysis

The freeway data were organized into separate files, with each file including traffic data for one detection station for a 24-hour period. Analysis of the freeway data was performed using the Statistical Package for Social Science software (SPSS version 10). The analysis of the data included generating speed confidence intervals for 14 locations along the freeway using the entire dataset. The speed confidence intervals represent the range of speeds that can be expected at these locations under “normal” traffic conditions. The speed confidence intervals were obtained for each 15-minute period and under different weather conditions. Table 2 presents an example of the hour-by-hour speed confidence intervals generated for the traffic at Broadway Ave.

Table 2. Speed Confidence Intervals (Broadway Ave. Milepost 53.92)

Time Interval	Eastbound Traffic		Westbound Traffic	
	Upper Limit	Lower Limit	Upper Limit	Lower Limit
Midnight - 1:00 AM	75	54	76	49
1:00 AM - 2:00 AM	75	54	77	47
2:00 AM - 3:00 AM	74	53	79	44
3:00 AM - 4:00 AM	74	54	77	45
4:00 AM - 5:00 AM	77	56	75	49
5:00 AM - 6:00 AM	77	57	76	53
6:00 AM-7:00 AM	76	54	77	52
7:00 AM - 8:00 AM	75	49	74	53
8:00 AM - 9:00 AM	76	52	74	52
9:00 AM - 10:00 AM	75	51	75	51
10:00 AM - 11:00 AM	75	52	75	51
11:00 AM - Noon	77	52	75	51
Noon - 1:00 PM	77	52	74	52
1:00 PM - 2:00 PM	75	53	74	50
2:00 PM - 3:00 PM	76	52	75	51
3:00 PM - 4:00 PM	75	53	76	45
4:00 PM - 5:00 PM	77	48	72	48
5:00 PM - 6:00 PM	77	48	74	51
6:00 PM - 7:00 PM	77	52	74	50
7:00 PM - 8:00 PM	75	51	75	54
8:00 PM - 9:00 PM	76	52	75	53
9:00 PM - 10:00 PM	75	54	76	52
10:00 PM - 11:00 PM	76	51	77	51
11:00 PM - Midnight	76	51	76	52

2.2 Traffic Flow Profiles

The traffic data were first analyzed to determine traffic flow characteristics on the Treasure Valley freeway system. Figures 4 and 5 present the average hourly traffic volumes during the morning and afternoon peak periods at different locations along Eastbound and Westbound I-84. The morning peak period was considered to be from 7:00 AM to 9:00 AM and the afternoon peak period was considered to be from 4:00 PM to 6:00 PM. Figures 6 and 7 present the volume/capacity ratio at the same locations for both the morning and afternoon peak periods. The capacity of was obtained using the following equation:

$$C = NC_{ideal} f_{HV} f_P \text{ where:}$$

N is the number of lanes

C_{ideal} is the ideal capacity and was assumed 2000 vph.

f_{HV} is the heavy vehicle adjustment factor based on the percent of heavy vehicles in the traffic. In the morning peak, the average HV percentage was 3.21%, whereas the average HV percentage increased to 5.4% in the afternoon peak period. Using these percentages, the adjustment factors were 0.987 and 0.966 for the morning and afternoon peak, respectively.

f_P is the driver population factor and was assumed 1.0, as most of the morning and afternoon peak periods drivers are commuters and familiar with the freeway.

As can be seen from these figures, the v/c ratio for most parts of the freeway is less than 0.73, indicating stable flow conditions with a level of service ranging from A to C. However, a segment of the freeway from milepost 48 to milepost 49 and from milepost 53 to milepost 55, the v/c ratio ranged from 0.73 to 0.91, indicating a high density and near capacity flow conditions with a level of service D.

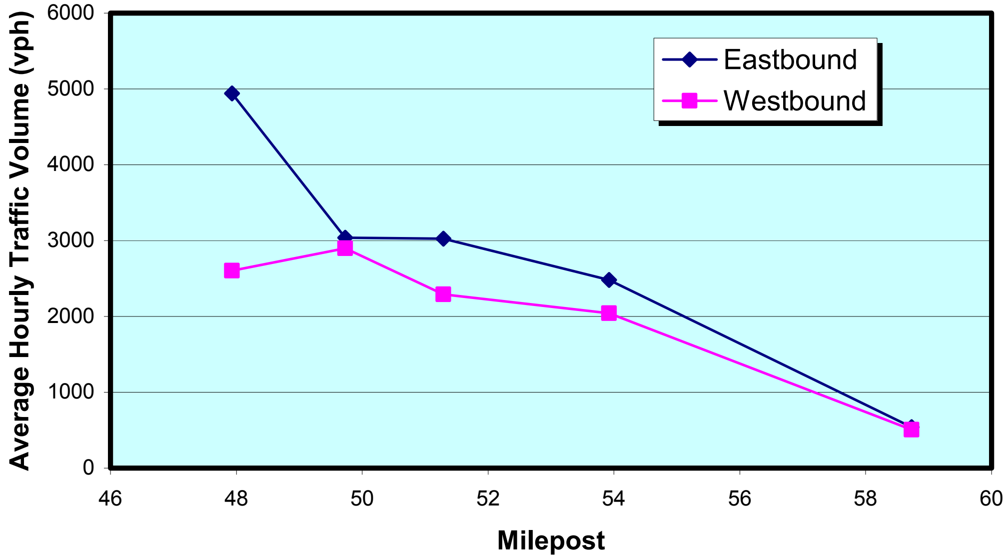

Figure 4. Average Hourly Traffic Volumes (Morning Peak Period)

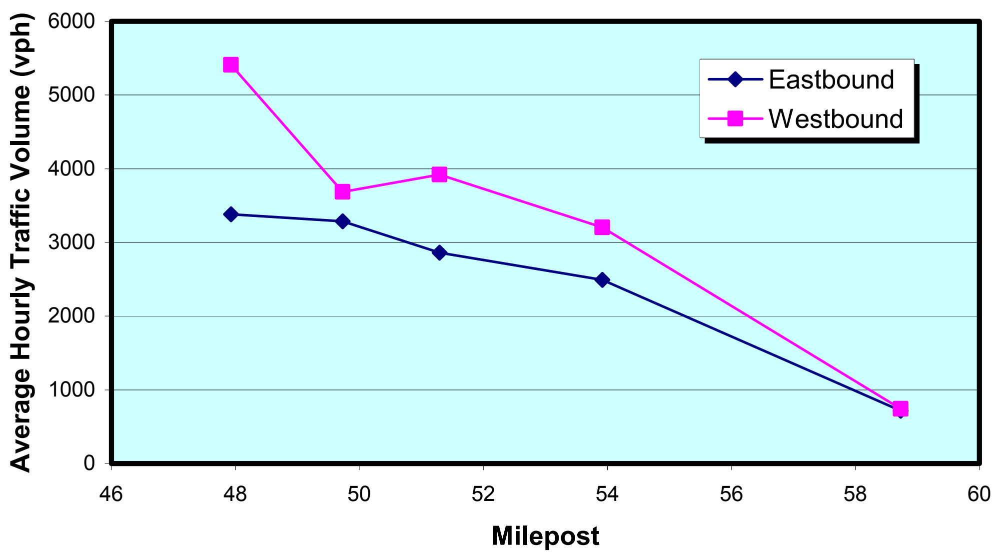

Figure 5. Average Hourly Traffic Volumes (Afternoon Peak Period)

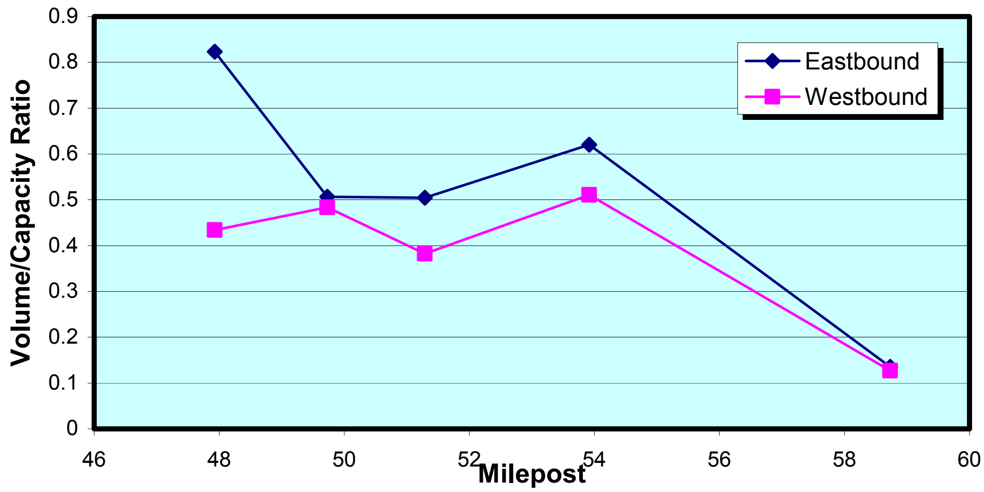

Figure 6. Volume/Capacity Ratio (Morning Peak Period)

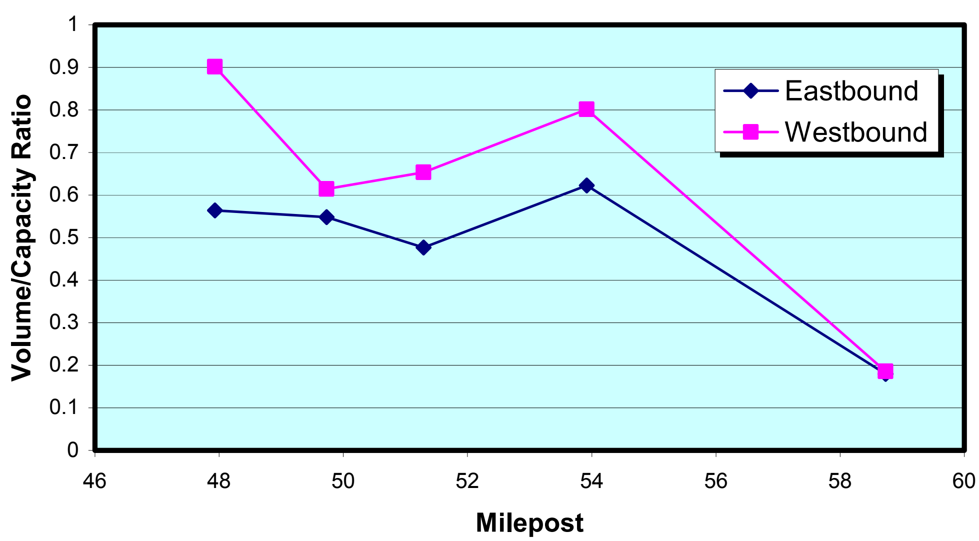

Figure 7. Volume/Capacity Ratio (Afternoon Peak Period)

Figure 8 presents the 24-hour volume variation for the Westbound traffic near Broadway Ave. The graph shows distinct morning and afternoon peak periods from 7:00 AM to 9:00 AM and from 4:00 PM to 6:00 PM, respectively. Figure 9 presents the monthly average daily traffic variation for the same location for the period from August 2000 through May 2001. The graph shows a slight decrease in traffic during the months of November, December, January and February, which might be attributed to the winter weather conditions during those four months.

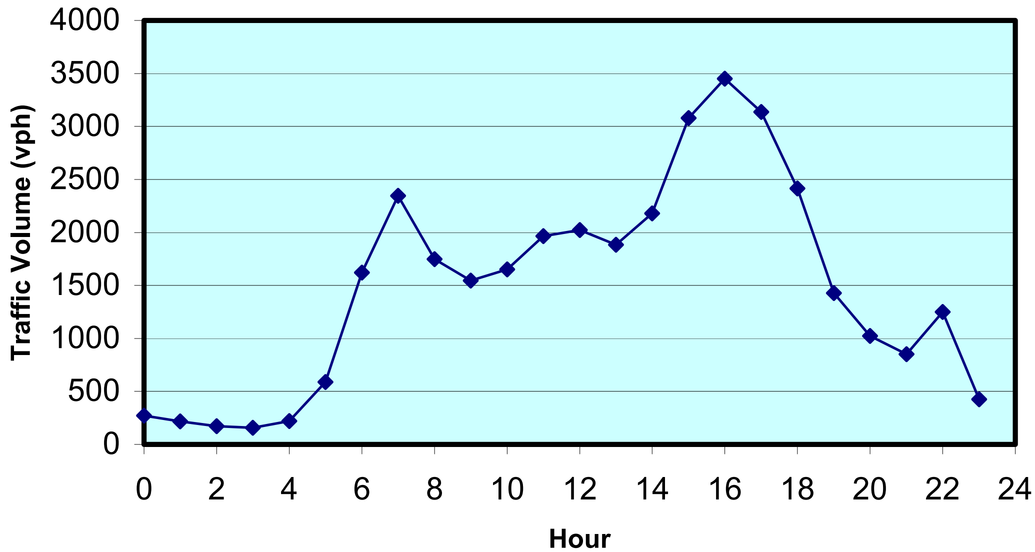

Figure 8. Hour-By-Hour Traffic Volumes for WB I-84 at Milepost 53.92 (Broadway Ave.)

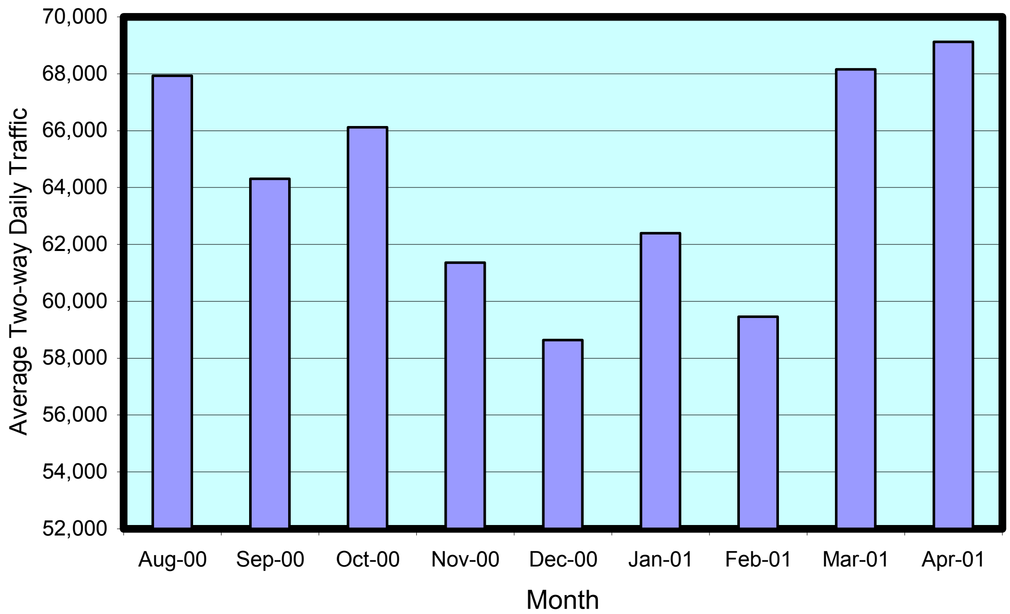

Figure 9. Average Two-Way Daily Traffic at Broadway Ave. (August 2000 – May 2001)

2.3 Speed Profiles

Figures 10 and 11 present the average speed during the morning and afternoon peak periods at different locations along Eastbound and Westbound I-84. The average speed during the peak periods ranged from 59 mph to 61 mph, which is close to the free-flow speed of 64 mph. This again indicates that the freeway operates under stable free-flow conditions. The average speed in the congested areas ranged from 49 to 54, indicating a high density with near capacity flow conditions.

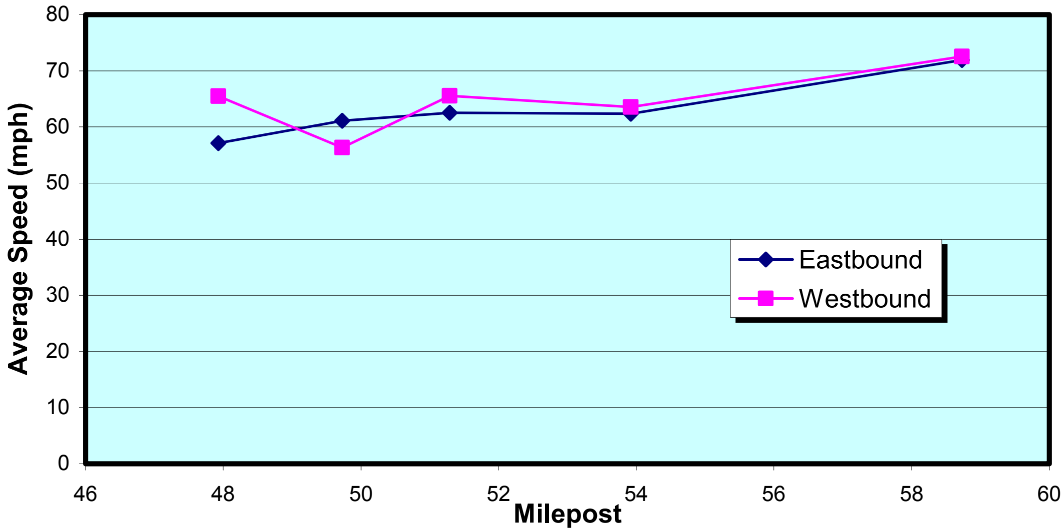

Figure 10. Average Hourly Traffic Volumes (Morning Peak Period)

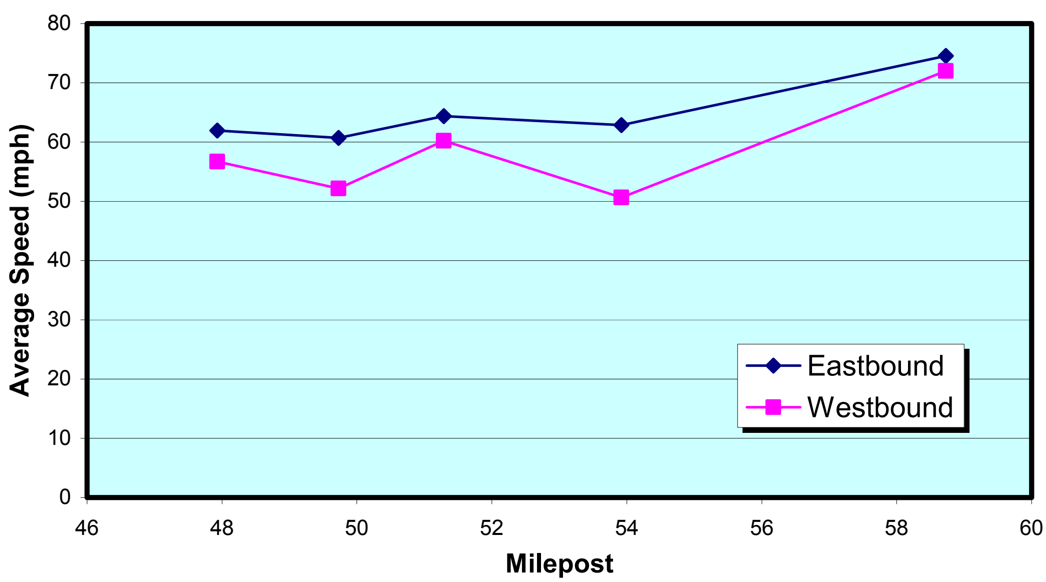

Figure 11. Average Hourly Traffic Volumes (Afternoon Peak Period)

The same conclusion can be drawn from Figures 12 and 13, which show the 24-hour speed profiles at Broadway Ave. and Five Mile Road, respectively. At Broadway, in the high-density area, the average speed during the non-peak period was 63.4 mph, representing stable free-flow conditions; whereas the average speed during the afternoon peak period was 52.9 mph, indicating high-density and near capacity flow conditions. At Five Mile Road, the average speeds during the non-peak and morning peak periods were 63.1 mph and 58.2 mph, respectively. This again indicates that traffic at this location is functioning in a stable free-flow condition during both the peak and the non-peak periods.

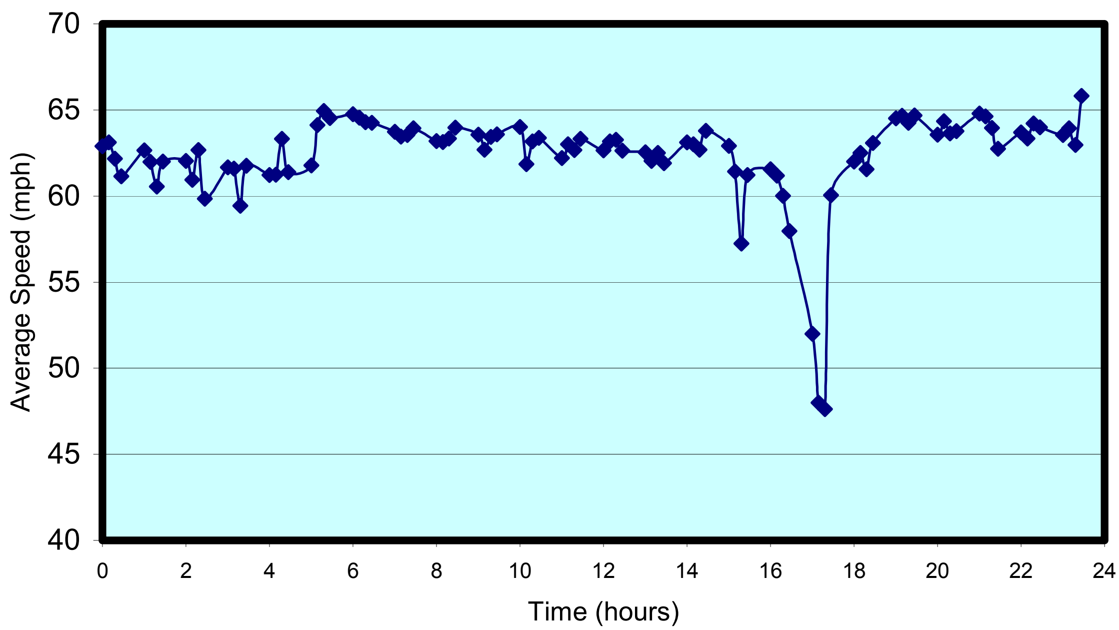

Figure 12. Average Speed Profile for Westbound Traffic at Broadway Ave

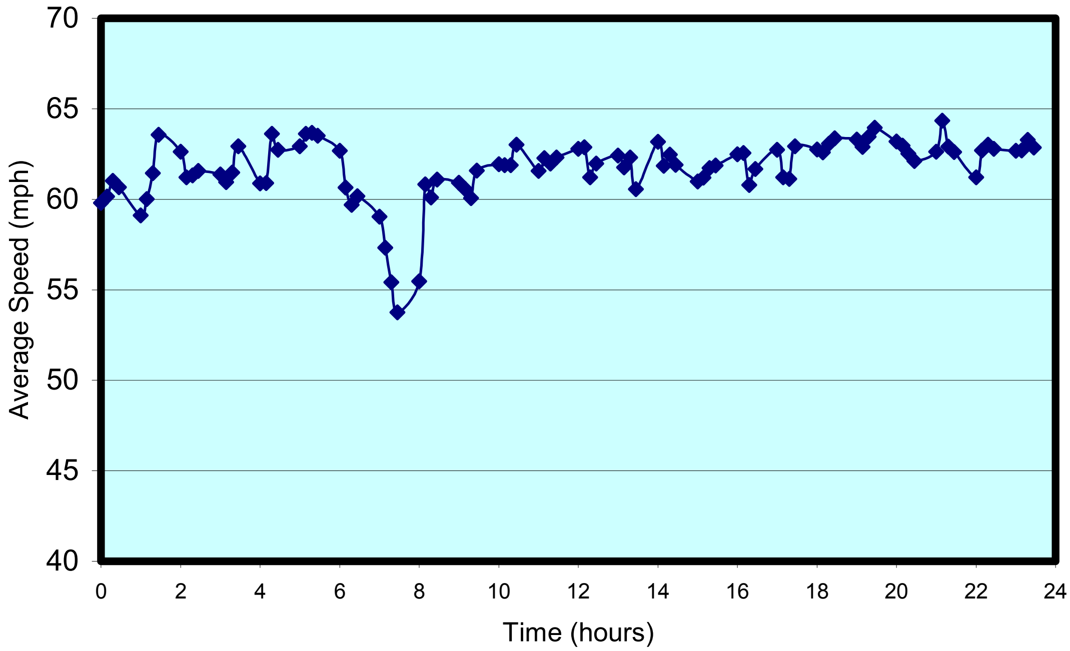

Figure 13. Average Speed Profile for Eastbound Traffic at Five Mile Road

It was also important to document changes in the average speed under different weather conditions. Figure 14 shows the speed profile at Broadway on January 19, 2001. The weather report on that date for the Boise area indicated snowfall beginning at 11:00 AM. As can be seen in the figure, there is a significant reduction in the average speed during snowy weather conditions. The average speed during this period dropped from 62.3 mph to 43.1 mph. The overall average reduction in speeds for all locations during snowy weather conditions was 17.3 mph. During rainy weather conditions, however, the reduction in the freeway operational speed was less drastic and averaged 1.8 mph.

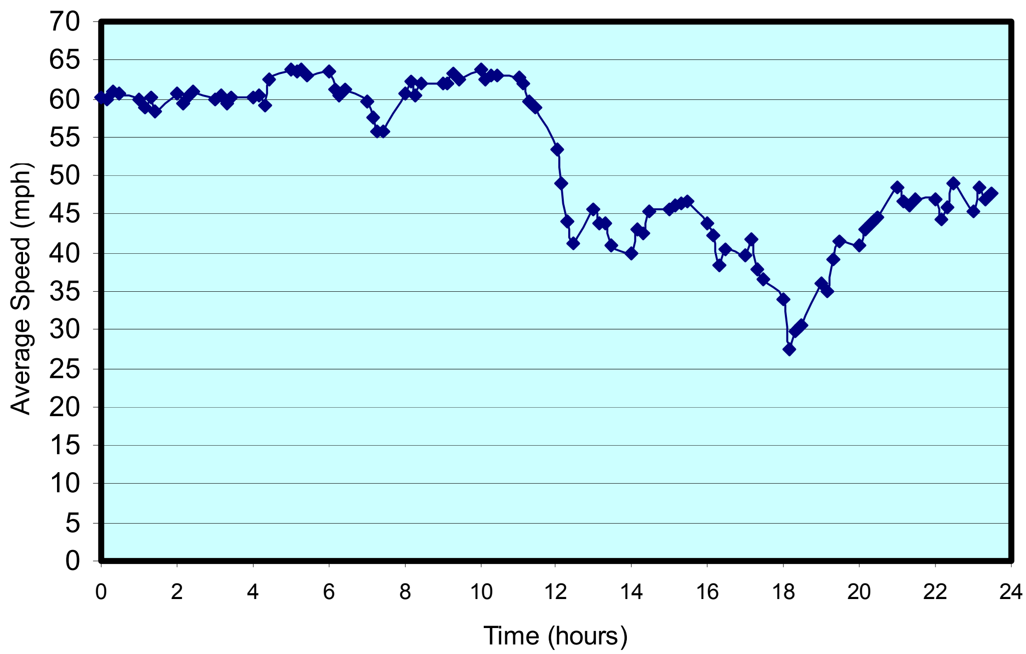

Figure 14. Average Speed Profile for Eastbound Traffic at Five Mile Road During Snowy Weather Conditions

2.4 Vehicle Mix

The objective of this part of the analysis was to determine the percentage of Heavy Vehicles (HV) in the traffic during different time periods and at different locations. For this project, HVs were defined as vehicles with lengths exceeding 40 feet. Figure 15 shows the percentage of HV to the overall traffic throughout a 24-hour period at Broadway Ave. As can be seen, the percentage of HVs varies throughout the day, with peak HV traffic occurring between 1:00 AM and 4:00 AM (26.11%). The percentage of HVs averaged 4.31 % during the morning peak period and 6.32% during the afternoon peak period for the Eastbound traffic. These percentages were 5.11% and 7.67% for the Westbound traffic.

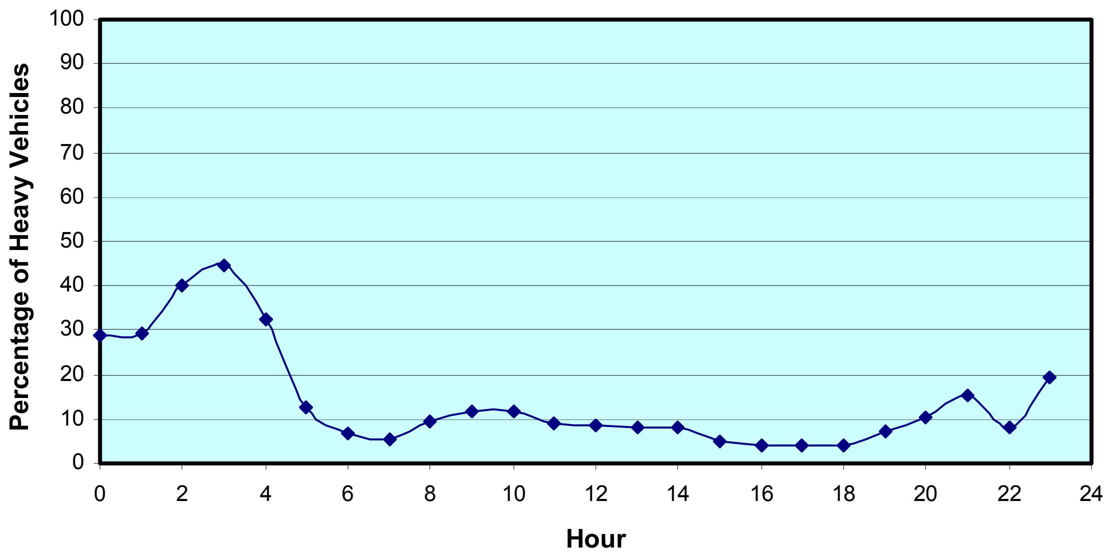

Figure 15. Percentage of Heavy Vehicles at Broadway Ave.

2.5 Traffic Flow Characteristics

The objective of this part of the analysis was to determine the traffic flow characteristics (speed, flow and density) and how they interrelate for traffic in the Treasure Valley area. Knowing how I-84 traffic flows is fundamental to understanding normal traffic conditions and the expected operational characteristics during incident situations. For example, queue forming and dissipating characteristics will depend on, among other factors, the jam density, the flow and density of normal traffic conditions and the capacity of the freeway. In order to reliably model incidents and their effect on the freeway, it is important to examine these traffic flow characteristics and how they interrelate.

Figure 16 presents the speed-density relationship using the 30-second aggregated data at Overland Rd. The graph indicates that the free-flow speed for traffic at this location ranges from 63 mph to 68 mph and the jam density ranges from 220 vpm to 260 vpm. Figures 17 and 18 present the flow-density and speed-flow relationship for the same data. The two graphs show that a maximum flow of 6000 vph (2000 vph/lane) occurs at density of 124 vpm and a speed of 34 mph.

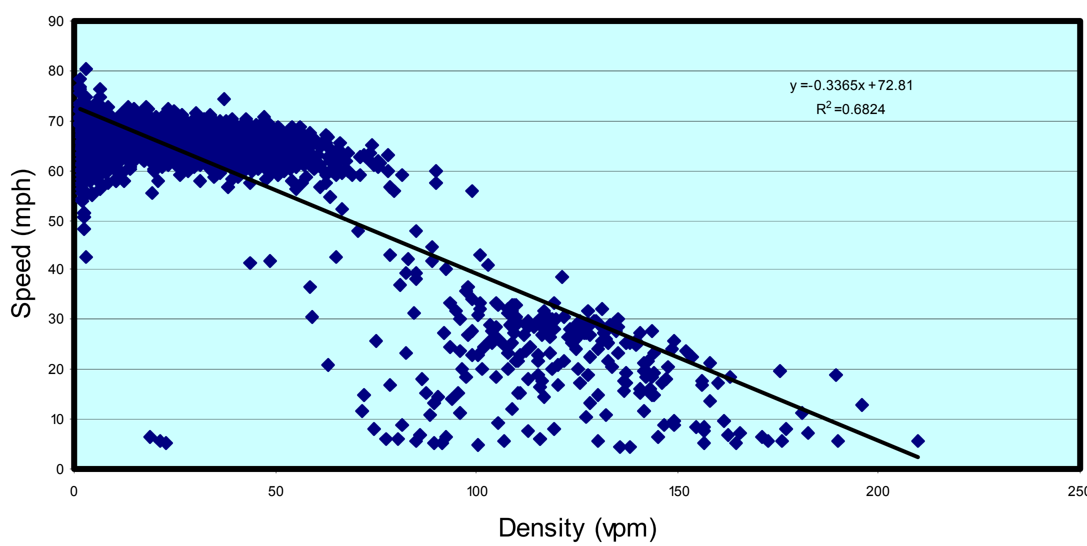

Figure 16. Speed/Density Relationship

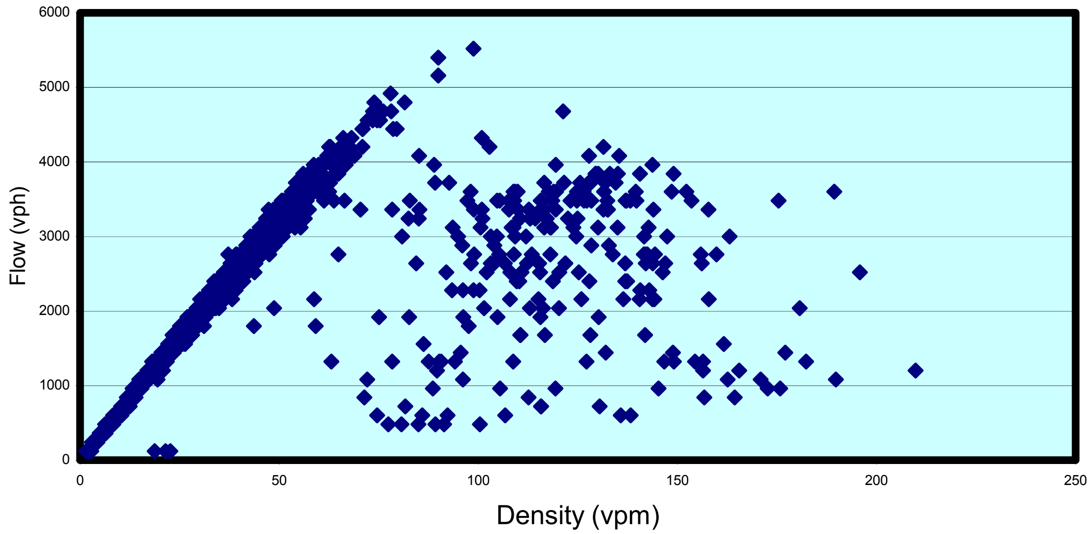

Figure 17. Flow/Density Relationship

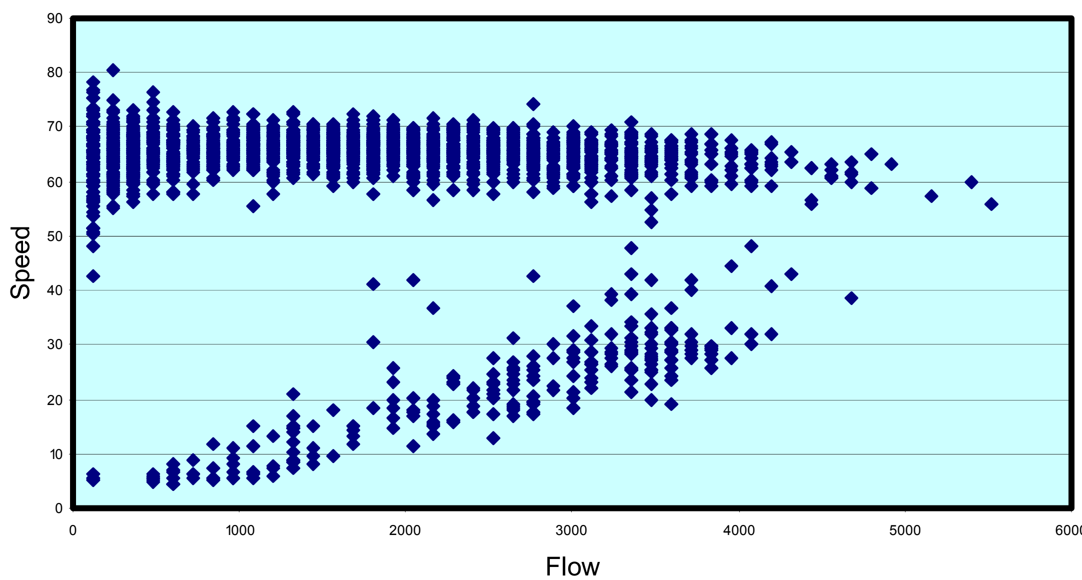

Figure 18. Speed/Flow Relationship

Another method for determining the jam density is to use the average vehicle length and a suitable vehicle clearance (a vehicle clearance during stoppage time was assumed to be 2 feet for this study). The ATR's raw data reports the vehicle length on a vehicle-by-vehicle basis and these data were used to obtain the average vehicle length during different time periods. The average vehicle length was then used to calculate the jam density during different time periods at different locations. Table 3 presents a summary of the results of this analysis. As can be seen, the jam density obtained through the vehicle length during the peak periods ranged between 209 vpm and 252 vpm. These results are very consistent with the jam density values obtained from the speed-density relationship.

Table 3. Average Vehicle Length and Jam Density at Overland Road (Milepost 49.73)

Time Period	Average Vehicle Length (ft)	Jam Density (vpm)
12:00 AM to 2:00 AM	35.5	137.2
2:00 AM to 4:00 AM	39.3	124.9
4:00 AM to 6:00 AM	23.3	200.5
6:00 AM to 8:00 AM	17.9	252.3
8:00 AM to 10:00 AM	21.9	212.3
10:00 AM to 12:00 PM	22.0	211.0
12:00 AM to 2:00 PM	21.0	219.6
2:00 PM to 4:00 PM	19.8	231.4
4:00 PM to 6:00 PM	18.2	249.4
6:00 PN to 8:00 PM	19.3	236.3
8:00 PM to 10:00 PM	22.2	209.7
1:00 PM to 12:00 AM	25.8	183.0

Queue forming characteristics help to determine the speed in which the queue resulting from an incident travels upstream of the incident. The queue forming speed is also important in order to determine the expected queue length and whether, or when, the queue will spill back and block upstream ramps. This speed is an important element in any incident management plan. The shock-wave analysis and the speed-density and flow-density relationships were used to determine queue forming characteristics during incident situations. The speed of the backward-forming shock wave resulting from the reduction of the freeway capacity during incidents can be obtained using the following equation:

$$V_f = \frac{Q_B - Q_A}{K_A - K_B},$$

where:

Vf	is speed of backward-forming shock wave
QB and KB	are the traffic flow and density at the incident location
QA and KA	are the traffic flow and density upstream from the incident (normal traffic flow)

Results from the shock-wave analysis for the segment of Westbound I-84 between Orchard Rd. (milepost 51.29) and Overland Rd. (milepost 49.73) are summarized in Table 4. The table presents the expected queue forming speed resulting from incidents with different severity levels.

Table 4. Queue Forming Speed Resulting from Incidents for the Segment Between Orchard Rd. and Overland Rd.

Time Period	Volume (Veh)	Speed (mph)	Density (vpm)	Queue Forming Speed (mph)		
				Three-Lane Closed	Two-Lane Closed	One-Lane Closed
12:00 AM - 2:00 AM	469	59.24	3.96	-1.76	0.00	0.00
2:00 AM - 4:00 AM	345	59.87	2.88	-1.41	0.00	0.00
4:00 AM - 6:00 AM	2232	62.18	17.95	-6.11	0.00	0.00
6:00 AM - 8:00 AM	7286	61.34	59.39	-18.88	-11.11	-3.33
8:00 AM - 1000 AM	4553	60.67	37.52	-13.02	-4.44	0.00
10:00 AM - 12:00 PM	4109	61.05	33.65	-11.58	-3.13	0.00
12:00 PM - 2:00 PM	4768	61.33	38.87	-13.19	-4.89	0.00
2:00 PM - 4:00 PM	5080	61.33	41.41	-13.37	-5.47	0.00
4:00 PM - 6:00 PM	6574	60.70	54.15	-16.83	-9.15	-1.47
6:00 PM - 8:00 PM	4218	60.69	34.75	-10.46	-3.02	0.00
8:00 PM - 10:00 PM	2660	59.20	22.47	-7.10	0.00	0.00
10:00 PM - 12:00 AM	1287	59.55	10.81	-3.74	0.00	0.00

3. CURRENT INCIDENT CHARACTERISTICS FOR THE I-84 CORRIDOR

3.1 Incident Data Collection and Management

Incident data were obtained from ITD District 3 incident response logs, maintained by drivers of two incident response trucks. These trucks operate on I-84 and I-184 for three hours a day, during the morning and afternoon peak periods. The drivers of the response trucks note the approximate location and the time of the event. They also record the type of action taken for each event to which they respond. The study examined copies of the ITD incident response logs from September 2000 through June 2001.

A summary of the logs for one of the months is shown in Table 5. The incident data were entered into a Microsoft Access database that includes: time of incident, incident clearance time, direction of travel, incident location (milepost), type of incident, type of action, weather condition during the incident, and severity of the incident (minor or major incident). Minor incidents are those having minor or no impact on traffic flow conditions and include abandoned vehicles, debris on the freeway, and motorist assistance. Major incidents are single or multiple vehicle crashes that are likely to have an impact on traffic flow conditions.

Table 5. Incident Response Log – November 2000

INCIDENT RESPONSE LOG

NOVEMBER

Abandoned
Debris
Accident/Wreck
Motorist Assistance
Traffic Control

	47	48	49	50	51	52	53	54	55	56	57
11/1/00		8:17 AM(W)		7:40 AM		8:05 AM(E)			7:41 AM(W)		
11/2/00	6:42 AM(E) 8:21 AM(E)		5:30 PM(W)	6:13 PM(E)		7:18 AM 8:46 AM 4:00 PM(E)					
11/3/00	9:45 AM(W)			4:26 PM(E)		7:47 AM(E)	4:50 PM(W) 5:15 PM(W)			8:44 AM(E)	
11/6/00	6:10 PM(W)							8:10 AM(W)		6:41 AM(W)	
11/7/00				5:07 PM(W)				5:57 PM(W)			
11/8/00	4:26 PM(E)					8:56 AM(E)					
11/9/00	3:16 PM(W)				5:32 PM(W)						
11/13/00			3:18 PM(E)		6:53 AM(E)		3:54 PM(E)	8:07 AM(E)			
11/14/00		7:00 AM(W) 7:36 AM(W) 9:01 AM(E) 3:54 PM(E)	5:34 PM(W)					6:09 PM(E)	4:10 PM(E)		
11/15/00		7:50 AM(W) 3:45 PM(E) 6:20 PM(E)			7:40 PM(W)		4:15 PM(W)				
11/16/00		3:12 PM(E)	5:19 PM(E)			6:52 PM(W)		5:57 PM(E)		4:15 PM(E)	
11/17/00	7:38 AM(E)		3:58 PM(E)				8:11 PM(W)		5:40 PM(W)		
11/18/00	3:18 PM(W)		4:30 PM (E)								
11/20/00			6:11 PM(W)			6:35 AM(E) 4:07 PM(W)	5:38 PM(W)	7:19 AM(W)			
11/21/00								5:45 PM(W)			
11/22/00	6:39 AM(E)					8:04 AM(W)					
11/24/00				3:25 PM(E) 3:28 PM(E)							
11/27/00	4:23 PM(W)	5:34 PM(W)			4:56 PM(E)						6:54 AM(W)
11/28/00	7:21 PM(W) 8:30 AM(W)		8:27 PM(W) 4:21 PM(W)					3:45 PM(W)			
11/29/00		8:45 AM(E)								5:01 PM(E) 5:14 PM(W)	
11/30/00		6:22 AM(W)									

3.2 Major Incidents Frequency and Location

Tables 6 and 7 and Figures 19 and 20 present the major incidents that occurred during the morning and afternoon peak periods on Eastbound and Westbound I-84, respectively. The data presented in the graphs cover the period from September 11, 2000 through February 28, 2001. A total of 50 major incidents were reported during this period, with 17 of them (34%) occurring during the month of January. Crashes that occurred during non-peak periods were not included in this study (the duration column is left blank if the incident duration was not provided by the incident report).

Table 6. Incidents on Eastbound I-84 (September 11, 2000 through February 28, 2001)

Date	Time	Mile Post	Type of Incident	Duration
9/12/2000	7:30	46	Accident	0:40
9/13/2000	6:53	51	2-Car Accident	
9/25/2000	16:10	39	6-Vehicle Accident	
9/26/2000	7:09	57	Accident	
10/17/2000	16:15	40	Accident	
10/18/2000	7:17	39	Accident.	0:48
10/27/2000	8:04	44	Accident	
11/8/2000	8:30	35	Slid Off	
11/13/2000	16:24	41	Accident	
11/14/2000	18:09	54	2-Vehicle Accident	1:46
11/29/2000	8:30	49	Chemical Spill	1:27
1/3/2001	17:25	54	Accident. Semi-truck	0:12
1/16/2001	8:54	38	Accident	
1/19/2001	16:47	44	Slide Off	0:22
1/19/2001	16:50	45	Slide Off Through Fence	
1/19/2001	18:25	45	3-Vehicle Accident	
1/29/2001	17:55	48	Accident	
1/29/2001	15:00	50	Accident	
1/29/2001	11:06	50	Accident called.	
1/30/2001	17:33	50	Accident	0:06
2/6/2001	16:30	51	Three-Vehicle Crash	0:35
2/8/2001	8:42	40	Crash	
2/8/2001	7:48	45	Accident	0:28
2/16/2001	16:33	40	Accident	0:21
2/22/2002	17:37	52	Three-Vehicle Crash	

Table 7. Incidents on Westbound I-84 (September 11, 2000 through February 28, 2001)

Date	Time	Mile Post	Type of Incident	Duration
9/27/2000	17:35	45	Accident (No Injuries)	0:08
10/5/2000	17:45	49	5-Vehicle Accident	1:25
10/10/2000	17:50	55	2-Vehicle Accident	
10/11/2000	18:05	50	Accident / Slide Off	0:12
10/16/2000	18:00	45	Accident (No Injuries)	
10/28/2000	7:57	53	2-Vehicle Accident	0:34
11/3/2000	17:15	53	2-Vehicle Accident	
11/21/2000	17:45	54	Accident	0:36
11/29/2000	17:48	44	Accident (No Injuries)	0:11
12/4/2000	15:25	44	2-Vehicle Accident	0:39
12/6/2000	18:25	50	2-Vehicle Accident	
12/20/2000	18:06	49	Accident	0:48
12/20/2000	15:34	57	Accident	
12/21/2000	17:35	43	Accident.	0:12
1/4/2001	7:50	46	Accident	0:06
1/8/2001	17:26	64	Accident	2:16
1/10/2001	17:57	45	2 Vehicle Accident	0:23
1/19/2001	18:47	48	2-Vehicle Accident	0:28
1/19/2001	13:29	51	Multi-Vehicle Accident	
1/25/2001	17:25	44	2-Vehicle Accident	0:10
1/29/2001	14:37	49	Accident	1:24
1/29/2001	9:58	59	Accident	0:27
2/6/2001	17:28	53	Accident	0:04
2/26/2001	7:06	52	Accident	0:07
12/7/2000	17:48	52	2-Vehicle Accident	1:47

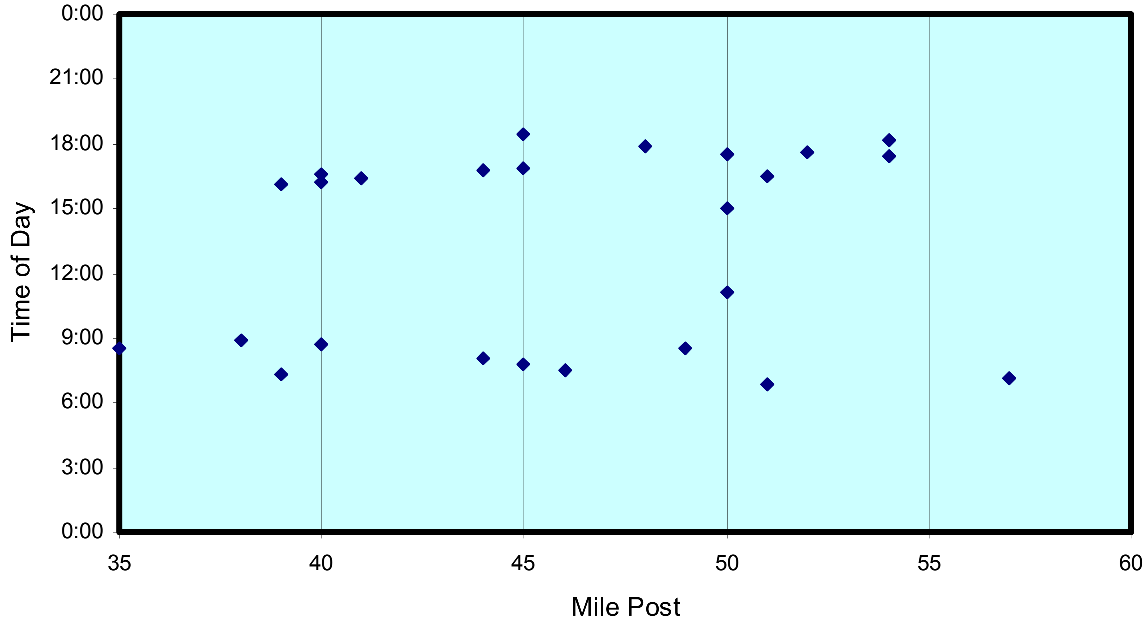

Figure 19. Major Incidents on Eastbound I-84

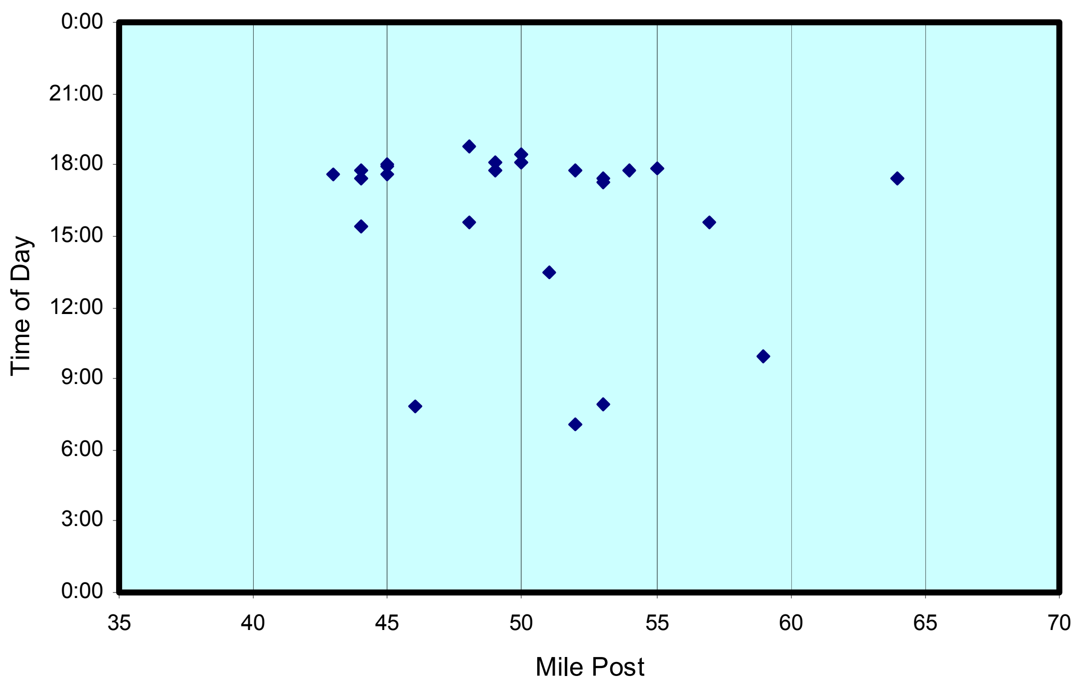

Figure 20. Major Incidents on Westbound I-84

3.3 Effect of Major Incidents on Freeway Flow Conditions

The objective of this part of the analysis was to examine the effect that major incidents had on traffic flow conditions, as reported by the ITD ATRs. For each of the 50 major incidents presented in Figures 19 and 20, volume and speed data for detection stations located upstream and downstream from the incident location, as reported in the incident log, were examined. Figures 21 through 25 show examples of incidents' effects on the speeds recorded at upstream and downstream detectors.

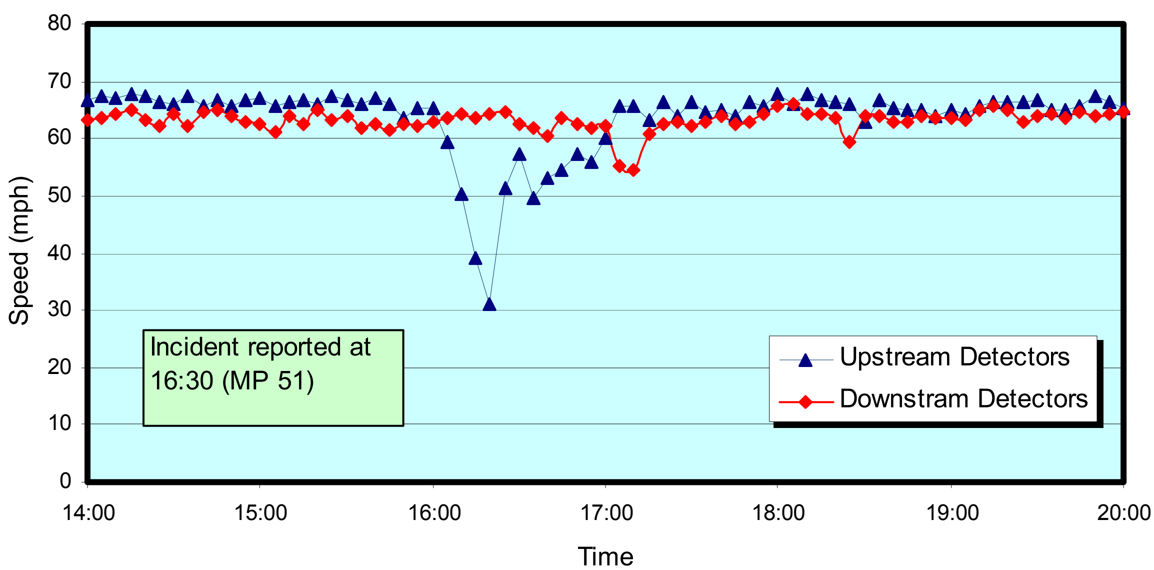

Figure 21. Incident occurred on EB I-84 on 2/6/2001 (Duration 0:35)

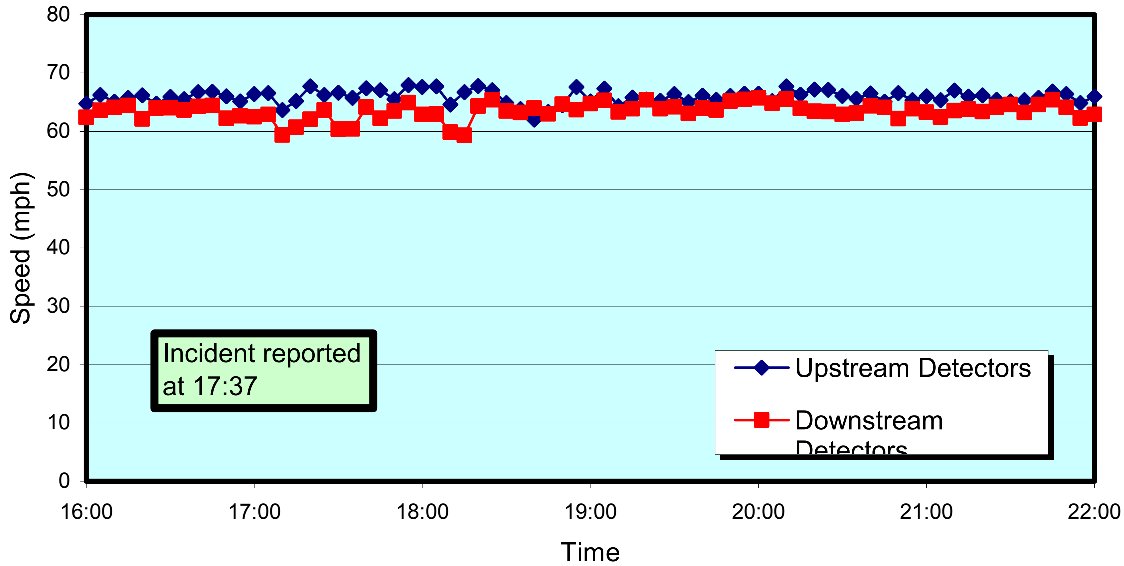

Figure 22. Incident Occurred on EB I-84 on 2/22/2001 (no duration available)

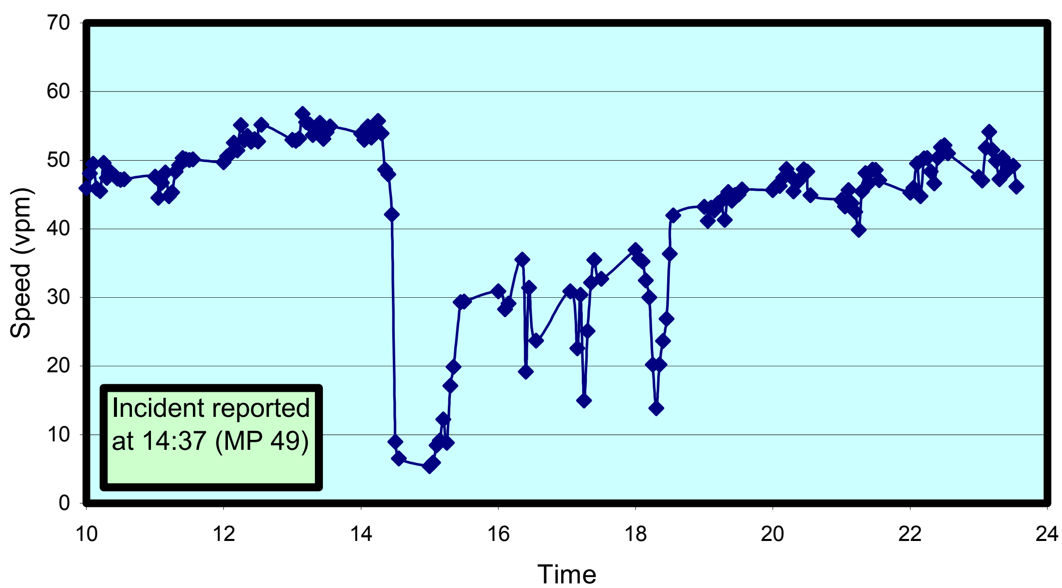

Figure 23. Incident Occurred on WB I-84 on 1/29/2001 (Duration 1:24)

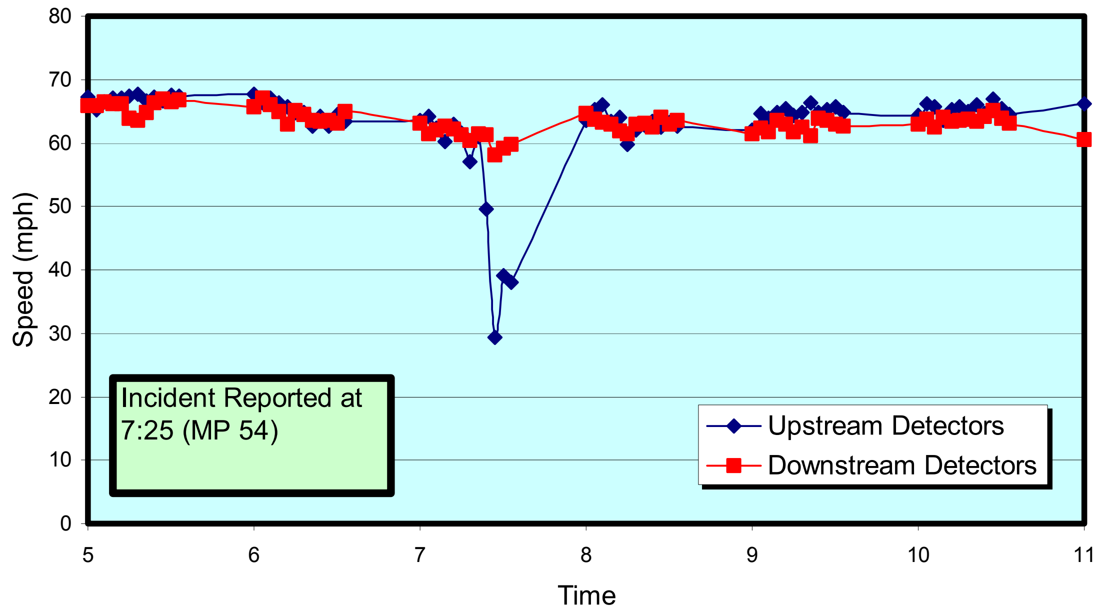

Figure 24. Incident Occurred on EB I-84 on 1/3/2001 (Duration 0:12)

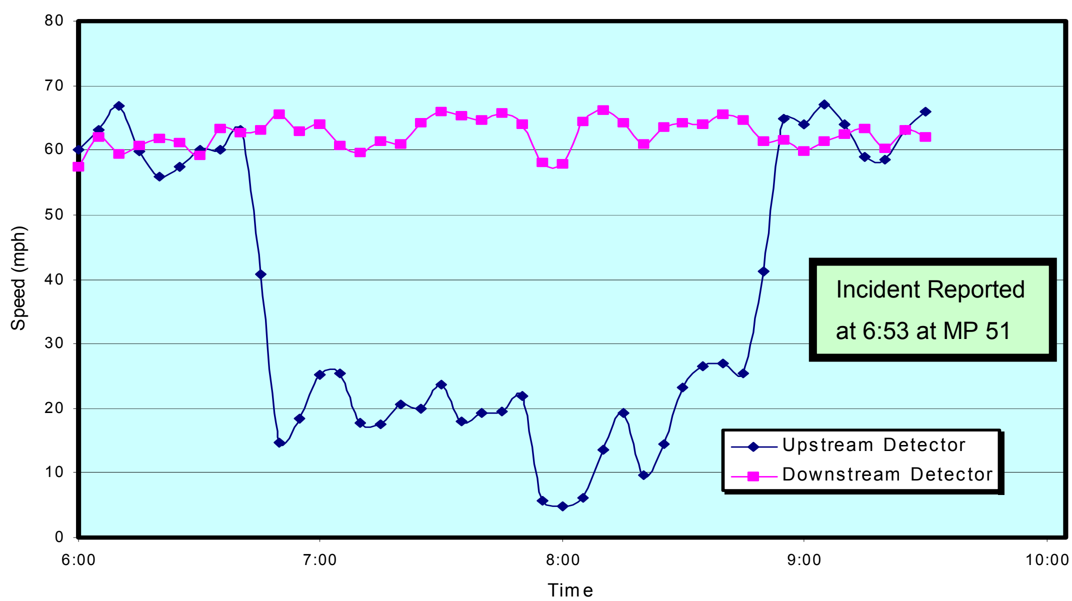

Figure 25. Incident Occurred on EB I-84 on 9/13/2000 (no duration available)

As can be seen in the figures, some of the incidents did not register any change in speeds or volumes recorded by the detection stations. This was clear for incidents that occurred a relatively long distance from the upstream detectors and/or that lasted for short periods of time. This indicates that, while these incidents might have considerable effect on the traffic flow conditions at the incident locations, their effects were not severe enough to cause changes at the locations of the detectors. On the other hand, incidents that required freeway closure for a considerable amount of time had a significant effect on the speeds and volumes recorded at the detector stations.

4. IMPLEMENTED INCIDENT DETECTION ALGORITHMS

Six algorithms were examined in the first phase of the incident detection research. They are:

- Mean Speed Algorithm implemented by Transcore
- Mean Speed Algorithm – Modification One
- Mean Speed Algorithm – Modification Two
- Difference in Speed with Persistence Check Algorithm implemented by Transcore
- Difference in Speed with Persistence Check Algorithm – Modification One
- California Algorithm #8 developed by CALTRAN

The six algorithms are described in the sections that follow.

4.1 Mean Speed Algorithm – TRANSCORE

The first algorithm tested was the Mean Speed Algorithm obtained from Transcore. Transcore has implemented this algorithm in the Milwaukee Advanced Traffic Management System. The algorithm defines four states used to describe traffic: incident-free, incident tentative, incident confirmed, and incident continuing. Figure 26 depicts the logic of the algorithm used by this method.

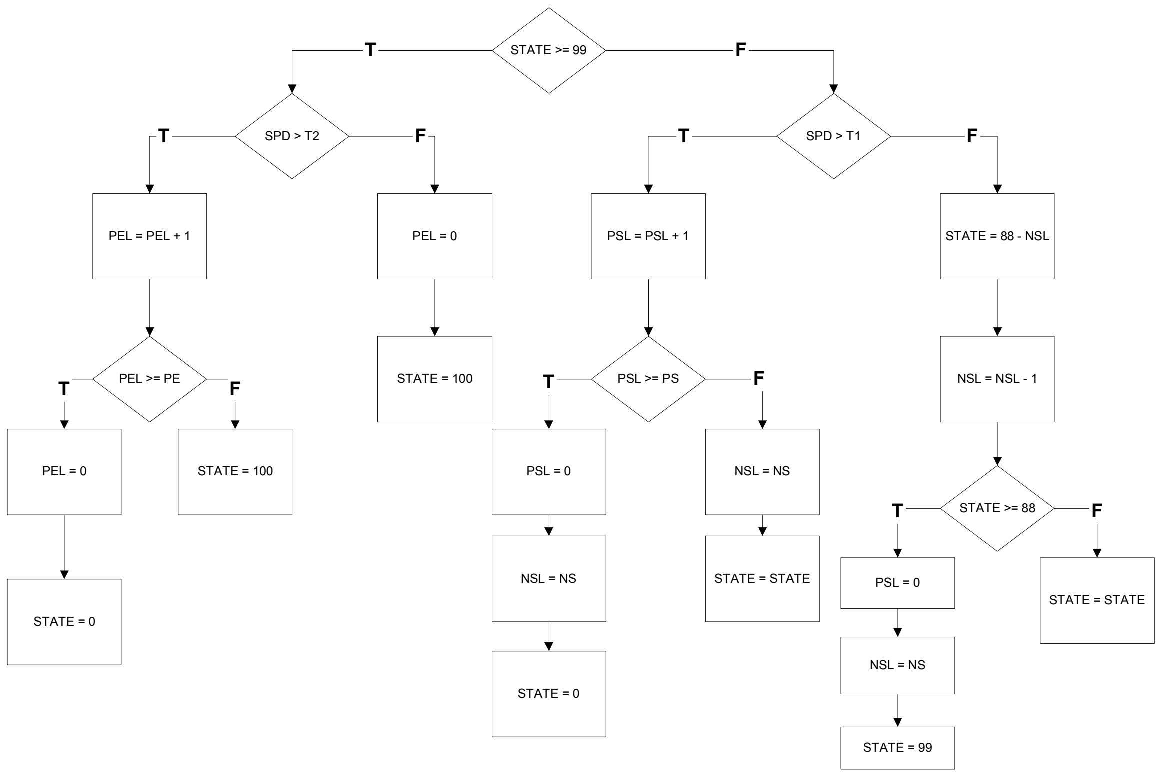

Figure 26. Mean Speed Algorithm – Transcore

The process starts with the traffic at a detector station in a certain state. The incident-free state is given a value of zero. The state of the traffic at the start of the algorithm is assumed to be incident-free. The traffic state will then transition to other states or remain at the incident-free state, depending on the value of the mean speed of traffic at the station and various parameter values chosen by the user.

From an incident-free state the state of traffic can either transition to a tentative incident state or remain as incident-free. The transition to a tentative incident state will occur only when the mean speed of traffic at the location goes below a user-defined threshold T1. If the speed remains below this threshold for a user-defined number of consecutive intervals, NSL, the state will become confirmed. Conversely, if the speed remains above this threshold for a certain number of consecutive intervals specified by the variable PS, the state will revert back to an incident-free state. Once an incident is declared to be confirmed, the state of traffic can either remain as a continuing incident or return to an incident-free state depending on whether or not the mean speed exceeds the threshold T2.

If the mean speed remains below T2, the incident state is said to be continuing. But if the mean speed is higher than T2, it has to remain at that level for a certain number of consecutive intervals before the state of traffic is declared to be incident-free. The required number of consecutive intervals is specified in the variable PE.

To summarize, in the Transcore Mean Speed Algorithm, once the mean speed of traffic goes below a certain threshold a tentative incident is declared. The state of traffic can either transition to an incident-confirmed state from the tentative incident state, or revert back to an incident-free state depending on the fulfillment of certain specified conditions.

4.2 Mean Speed Algorithm – Modification One

The mean speed algorithm described above was modified in two ways for the purpose of this research. The Scope of Work for this project requires the testing of existing algorithms, not the development of new algorithms. The two modifications of the Mean Speed Algorithm that will be described in this and the next section are not entirely new algorithms, they are just minor modifications to the Transcore algorithm to either simplify it or improve it, to make it more suitable to the I-84 data set.

In Modification One, the objective was to simplify the algorithm. The states of traffic flow have been reduced from four to two—incident and no incident states. At every time interval the mean speed over all lanes is compared with two threshold speeds—T1 and T2. If the mean speed of traffic goes below T1, the state of the traffic is considered to transition from incident-free state to incident state. An incident state is declared to occur if the mean speed of traffic remains below T1 for a user-defined number of consecutive intervals. The variable that stores this number is denoted as PE in the flow chart shown in Figure 27.

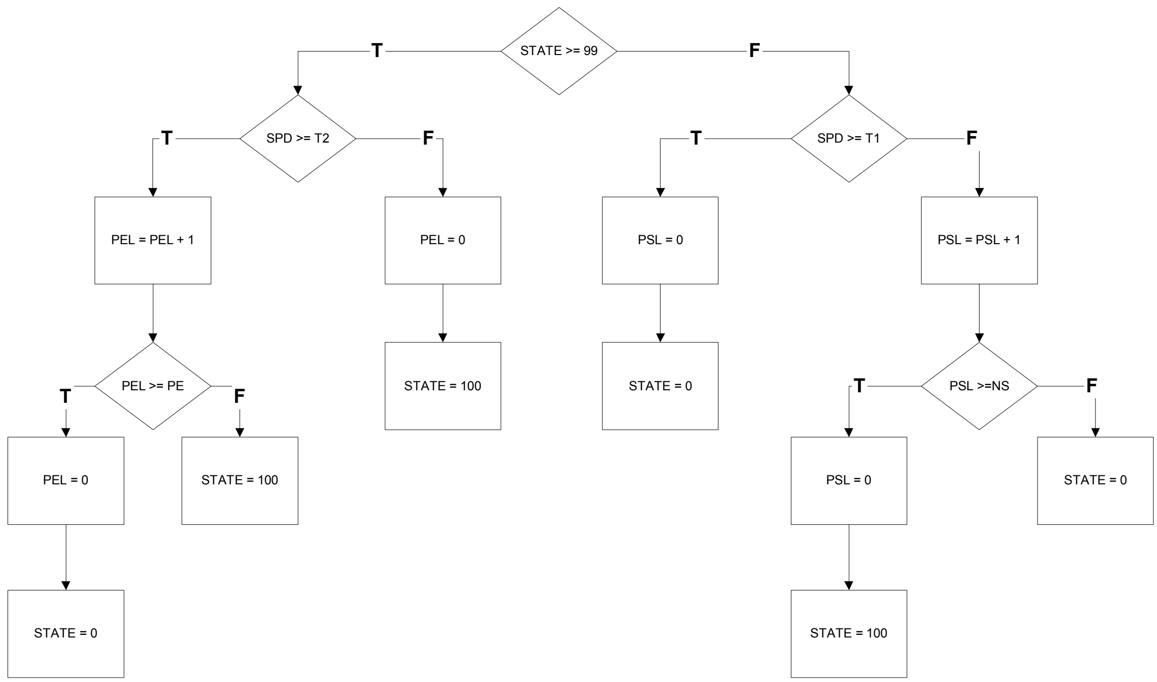

Figure 27. Mean Speed Algorithm – Modification One

Once the state of traffic enters an incident-present state, the mean speed has to exceed another threshold speed, T2, for a certain number of consecutive intervals. This number is denoted by NS in the flow chart. T2 is chosen to be higher than T1 so that the state of the traffic cannot improve to an incident-free state after an incident is declared unless the mean speed is unquestionably higher than it was before entering the incident-present state.

The state of the traffic can have two possible values, 0 and 100. State 0 is used to denote an incident-free state, while state 100 is the incident state. SPD is the mean speed for the direction during the last time interval. PEL stores the number of consecutive intervals during which the mean speed was higher than T2; this is the condition required for the algorithm to change the state from incident to incident-free. PE is the threshold that PEL has to cross for the state to change to incident-free. PSL is similar to PEL and keeps track of the number of consecutive intervals during which the mean speed is below the threshold T1. If PEL exceeds the user-defined value, NS, it is considered to be an incident state.

4.3 Mean Speed Algorithm – Modification Two

Modification Two is different from the Transcore algorithm in two respects. First, the number of states used is three: incident-free, tentative incident, and confirmed. The second and more significant difference is the logic used in transitioning from a tentative incident state to an incident-confirmed state. The logic used in reverting to an incident-free state from an incident-confirmed state is similar to the two algorithms described previously: when the mean speed is above the threshold T2 for a certain number of consecutive intervals the state of traffic returns to an incident-free state.

The transition from a tentative state to a confirmed state is based on the value of a variable defined as "RV" in Figure 28. The variable RV is defined as the ratio of difference between the mean speed over two consecutive time intervals and the running average of the mean speed over a certain number of time intervals. The value of RV is compared to a user-defined parameter denoted as RATIO. When RV exceeds this value, the state is considered to transition from tentative to confirmed.

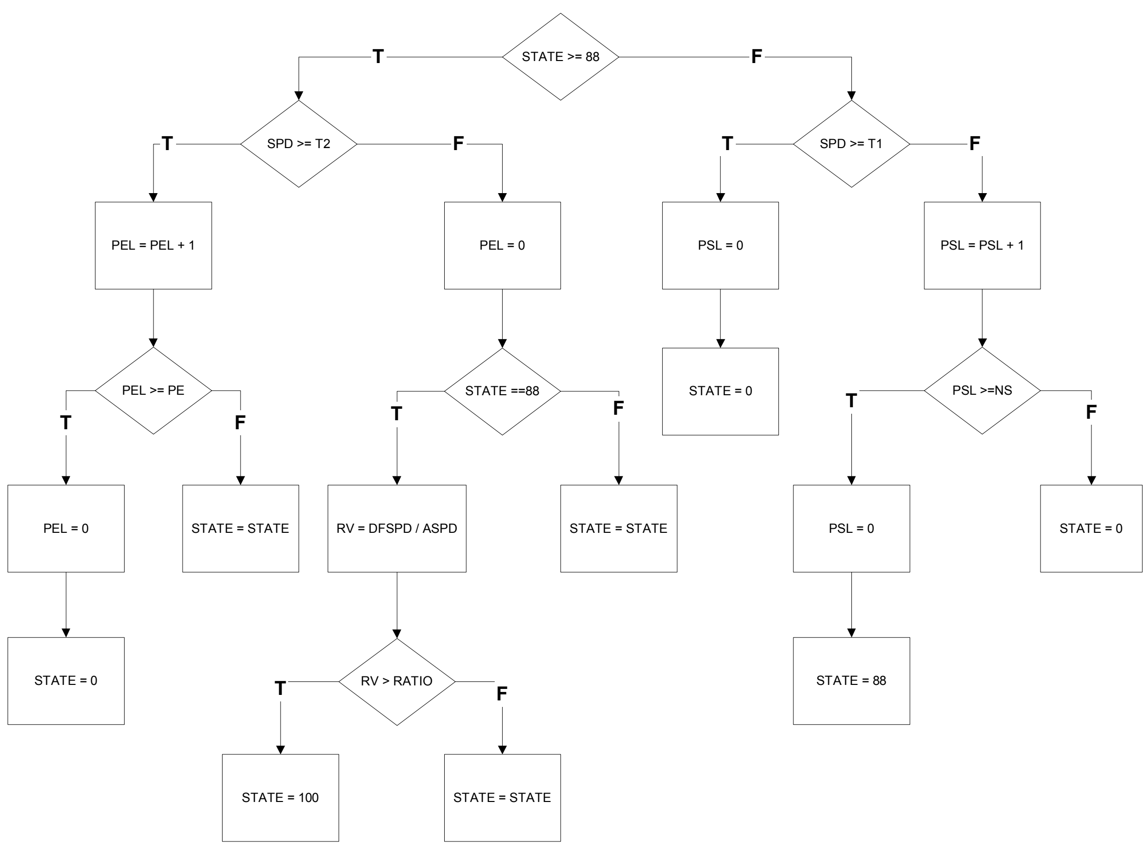

Figure 28. Mean Speed Algorithm – Modification Two

The idea behind the use of RV is to differentiate between an incident and normal recurring congestion conditions. In the first two algorithms this transition is based on the value of the mean speed being lower than a threshold for some consecutive number of intervals. But, such a condition can also be satisfied when the decrease in mean speed is due to normal congestion. The use of the variable Ratio defined above is designed to distinguish between these two conditions.

During data processing for this project it was observed that the reduction in mean speed due to an incident was more rapid than the reduction due to recurring congestion. The variable RATIO is expected to capture this distinction more accurately than the number of consecutive-intervals criteria used by the first two algorithms.

4.4 Difference in Speed with Persistence Check – Transcore

The two algorithms described in this section and section 4.5 use information from two detector stations, as opposed to the single detector station data used in the first three algorithms. The variables used are: SPDDF, SPDD, and SPDRDF. SPDDF is the difference in speed between the mean speeds at a detector station and its adjacent downstream section. The difference is computed by subtracting the downstream speed from the upstream speed. SPDD is the mean speed at the downstream station. Finally, SPDRDF is the relative difference in speed between a detector station and its downstream counterpart. The relative difference in speed is computed by subtracting the downstream mean speed from the upstream mean speed and dividing the result by the upstream mean speed. Transcore's algorithm is shown below, in Figure 29.

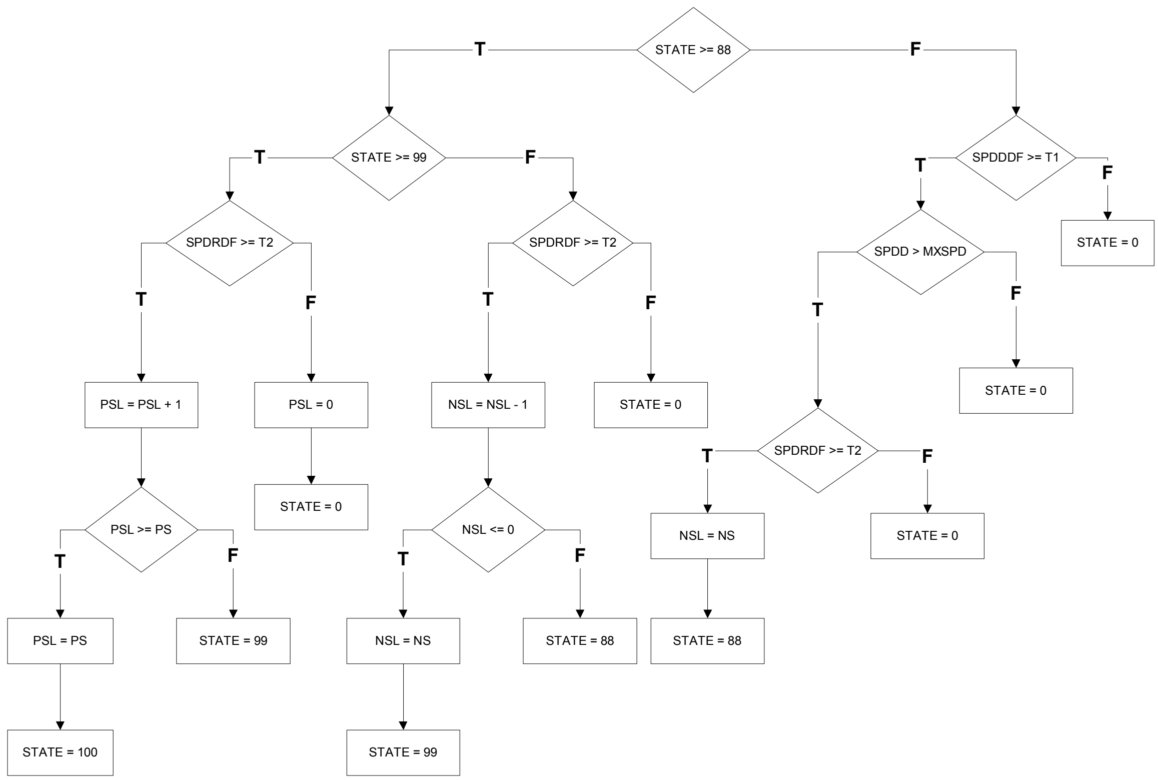

Figure 29. Differences in Speed with Persistence Check – Transcore

As with the Mean Speed algorithm, there are four possible traffic states in this algorithm: free, tentative, confirmed, and continuing. Assuming that at the start of the processing the traffic state is incident-free, the algorithm tests to see if the speed difference is greater than the user-specified threshold T1. If it is, the second level test is to see if the downstream mean speed is greater than a second threshold, MXSPD, which is the lowest speed allowed at the downstream station for an incident to be confirmed. If this is also true, then the last test is to test if the relative difference in speed is greater than the threshold T2. If all three of these tests are satisfied in a given time interval, a tentative incident event is declared. If the test fails in any of the three steps, the state is said to remain incident-free.

Once a tentative incident is declared, the relative speed difference has to exceed T2 for a few more consecutive intervals before an incident-confirmed state can be declared. The number of consecutive intervals required is specified by the parameter NS. If at any interval during this testing the relative speed difference goes below T2, the state of the traffic is declared to be incident-free.

Once a confirmed incident state is declared, the state at the next interval will either be incident-free or incident-continuing, depending on whether or not the relative speed difference is below T2. In the most recent algorithm obtained from TRANSCORE, the incident-confirmed state is said to exist for some consecutive number of intervals before a continuing-incident state is declared. The consecutive number of intervals used for this test is stored in the parameter PS. This is counter-intuitive, as one would find it more reasonable to declare an incident-continuing state if the situation required for a confirmed incident state persists at the next interval, instead of having to wait for PS number of times before declaring an incident-continuing state. But, this is what Transcore delivered and this is what was implemented at this phase of the study.

4.5 Difference in Speed with Persistence Check – Modification One

In Modification One, the Transcore algorithm described in Section 4.4 was modified to simplify it. The first modification, depicted in Figure 30, is the use of the speed difference (SPDDF) only to transition from an incident-free state to a tentative-incident state. This test has to be satisfied for a user-specified number of consecutive intervals before the tentative-incident state is declared. The number of consecutive intervals required for this test is stored in the parameter NS.

After a tentative-incident state is declared, the incident state is said to be confirmed only when the relative speed difference exceeds T2 for NS number of consecutive intervals. This requirement is similar to the one required by the Transcore algorithm, in which a tentative incident is not declared to be confirmed in the very next interval after attaining the tentative-incident state. The state is said to linger as tentative for a few more consecutive intervals before declaring a confirmed incident.

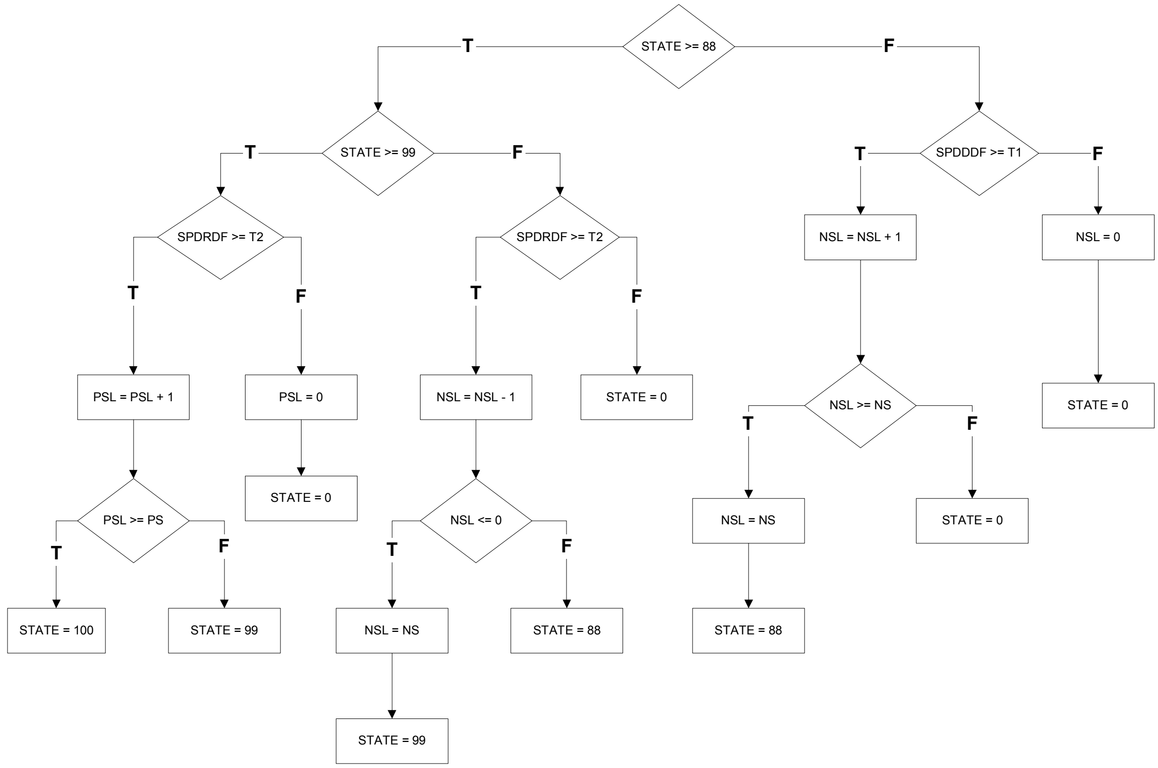

Figure 30. Difference in Speed with Persistence Check – Modification One

The test used to declare a continuing-incident state after the confirmation of an incident is again based on whether or not the relative speed difference exceeds T2. If it does for PS number of consecutive intervals, the state is declared to be continuing and not just confirmed. The comment made at the end of the Section 4.4 also applies here; the transition from confirmed to continuing is not made after one interval only, even though it appears more reasonable to do so. This logic was maintained in the modified algorithm also, since the goal was to make minimal modification to the algorithm obtained from external sources.

4.6 California Algorithm #8

The final algorithm tested in this first phase of the research is Algorithm #8 of the California group of algorithms, which were developed by the California Department of Transportation a few decades ago. As depicted in Figure 31, this algorithm defines eight states of traffic flow, which are described below.

The incident-free state is given a value of zero. States with values of one through five are used to describe compression wave conditions at the downstream station during the past one through five intervals, respectively. A tentative incident condition is given a state value of six. The incident-confirmed state has a value of seven, and the last remaining value of eight is given to the incident-continuing condition.

The other variables used in the algorithm are denoted by the following acronyms: OCCDF, OCCRDF, DOCC, and DOCCTD.

- OCCDF is the variable that stores the value of the difference in occupancies between a detector station and its downstream counterpart. This difference is also denoted as spatial occupancy difference.
- OCCRDF is the relative spatial occupancy difference. In other words, OCCRDF is OCCDF divided by the occupancy at the upstream station.
- DOCC is the downstream occupancy at the downstream station.
- DOCCTD is the relative temporal downstream occupancy. It is calculated by subtracting the occupancy at the downstream station during this period from the occupancy during the time interval two periods ago and dividing this difference by the occupancy at this location during the two-period ago time interval.

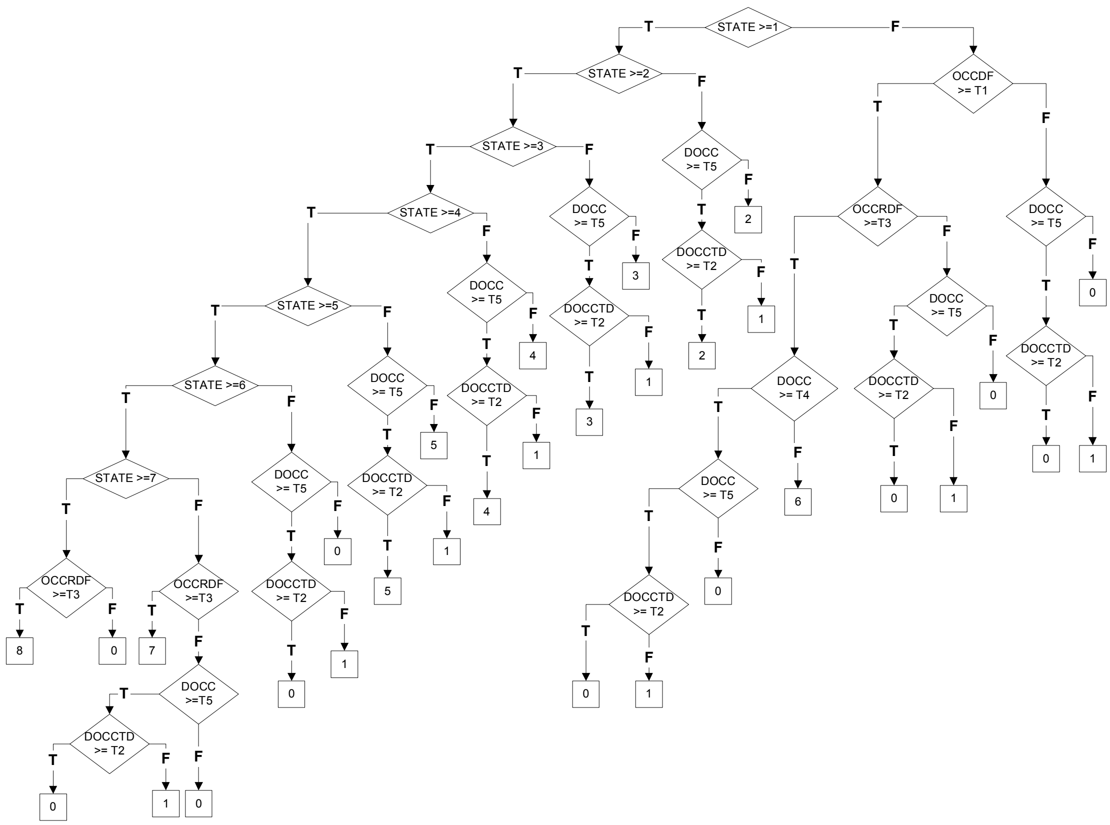

Figure 31. California Algorithm #8

The equations used to calculate the four variables described above make use of occupancies at various stations at various time intervals. Denote the occupancy at station (i) during time interval (t) as OCC(i, t). Then OCCDF = OCC(i, t) – OCC(i+1, t), OCCRDF = OCCDF/OCC(i, t), DOCC = OCC(i+1, t), and DOCCTD = [OCC(i+1, t-2) – OCC(i+1, t)]/OCC(i+1, t-2). Note that t-2 denotes the time interval two periods ago. If the time interval used is one minute, then t-2 would be the time interval two minutes ago.

The algorithm will require the user to specify the values of five parameter thresholds: T1 through T5. Assuming that the processing starts with an incident-free state (that is, with a state value of zero), three conditions have to be satisfied before a tentative incident is declared. The spatial occupancy difference, the relative spatial occupancy difference, and the downstream occupancy have to exceed or be equal to T1, T3 and T4, respectively. Once a tentative incident is declared, if the relative spatial occupancy difference, OCCRDF, exceeds T3 during the next time interval, the incident is confirmed. The incident is declared to be continuing during subsequent intervals, as long as this condition is satisfied during each of those intervals.

If the conditions described above are not satisfied, the state of the traffic flow is classified as incident-free or with a compression wave downstream during this or the last five intervals, depending on which of the various conditions shown in Figure 31 are satisfied.

5. ALGORITHM OUTPUT

5.1 Algorithm Implementation

The implementation of the algorithms and the conversion routines for the traffic flow data were performed in the Java programming language.

The first program that was written was the data conversion program. As mentioned previously, the raw individual vehicle records data provide speed and vehicle length information for each actuation in each lane. Processing of the raw data was needed for two reasons. First, some form of time aggregation was needed, since plotting individual speeds was not informative. Second, aggregation over lanes was also desired.

The time period used for aggregation by the algorithms described in Section 2 is either 30 seconds or one minute. For example, the California algorithm uses one-minute data; the other algorithms use 30-second data. So a convenient means of processing the data for various time-aggregation was needed. The data conversion program fulfilled that need by allowing the user to select this time. An image of the dialog box of this program is shown in Figure 32. In this dialog box, the user chooses a file to process and also chooses the aggregation to use in the processing.

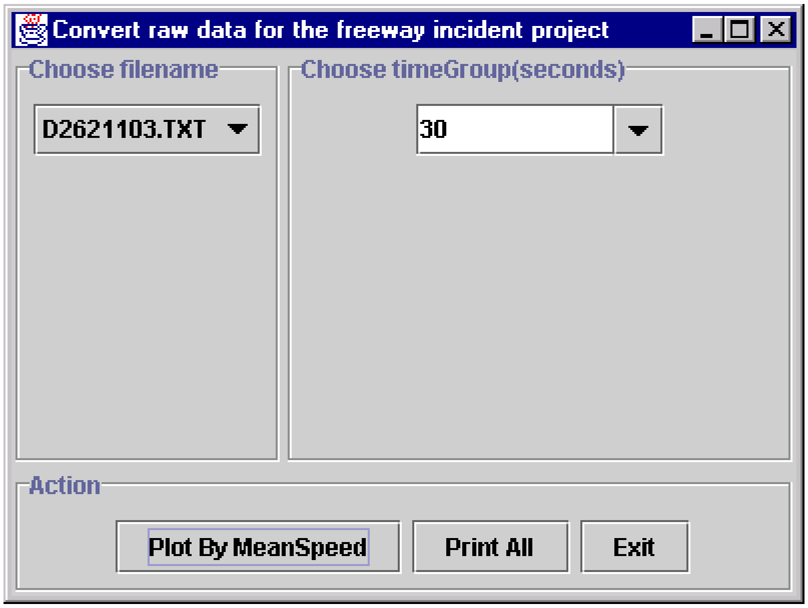

Figure 32. Data Conversion GUI

The raw data obtained from ITD were in the text file format. The file D2621103.TXT shown above is the data for detector station 262 for the 24-hour period preceding November 3, 2000. In other words, this particular file contains data for detector station 262 from 12:00 AM till 11:59:59 PM on November 2, 2000.

When the user clicks on “Plot By MeanSpeed” in the dialog box shown in Figure 32, the plot of the speed data aggregated over 30 seconds is shown. Figure 33 shows the plot.

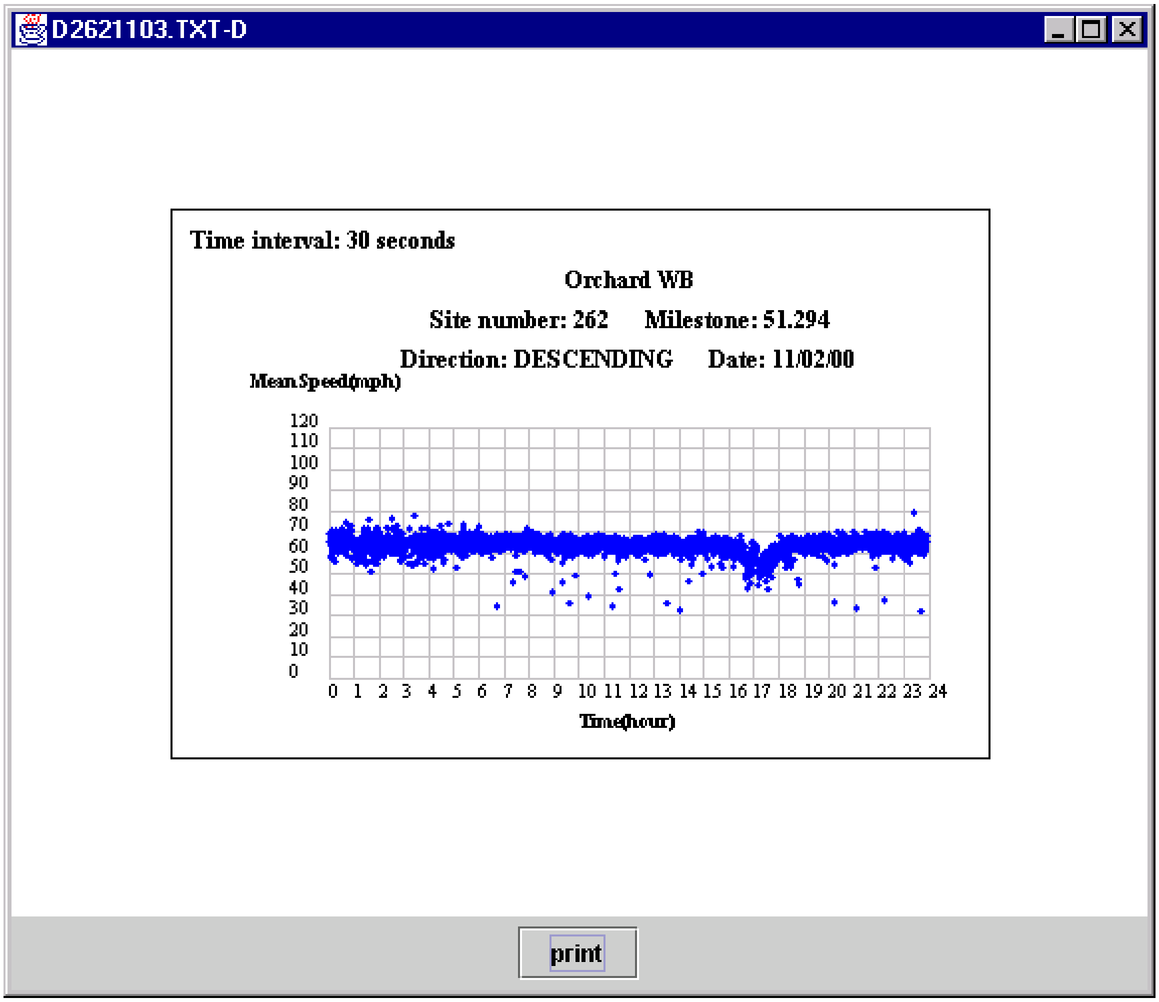

Figure 33. Mean Speed Plot

When a detector station covers both directions of travel, the “Plot by MeanSpeed” command generates plots for both directions of travel.

5.2 Output from Individual Algorithms

Output from the six algorithms studied in this project for a particular date and particular detector station(s) are presented in the following sections. Selection of the date is relatively straightforward; the user simply selects a date that has an incident in it.

The Mean Speed algorithms use data from just one station. The Difference-in-Speed algorithms, on the other hand, need data from adjacent stations. When data from adjacent stations are analyzed, one of the first requirements is that an incident has occurred at a location bounded by the two stations. It was also necessary that no other traffic-flow-altering factors existed in between the selected pair of stations. For example, Stations 260 and 261 do not constitute a good choice. At Station 260 there are five lanes, which reduce to three lanes at Station 261. So, if there is any slow down of traffic at Station 261 it may not be due to an incident but just due to the fact that there is a two-lane drop from 260 to 261.

A second factor to avoid while selecting a pair of consecutive detector stations is the existence of on or off-ramps between the two stations. A third factor is the distance between the two stations. If the distance between the incident and the station is too large, the disturbance in traffic flow caused by the incident may not be seen at the detector station. After considering these factors, the pair of detector stations chosen for analysis was 262 and 265. The discussions of output that follow will refer to either one or both of these stations.

5.2.1 Mean Speed Algorithm – TRANSCORE

The graphical user interface (GUI) of the program built for this algorithm is shown in Figure 34 below.

The user chooses the time of aggregation and the file to process. D2651104.TXT has the data for 11/03/00 at Broadway, Westbound (Station 262). The user then has to select values for the five parameters used in this algorithm. Any values can be typed in the text boxes. The output for the values selected in Figure 34 is shown in Figure 35.

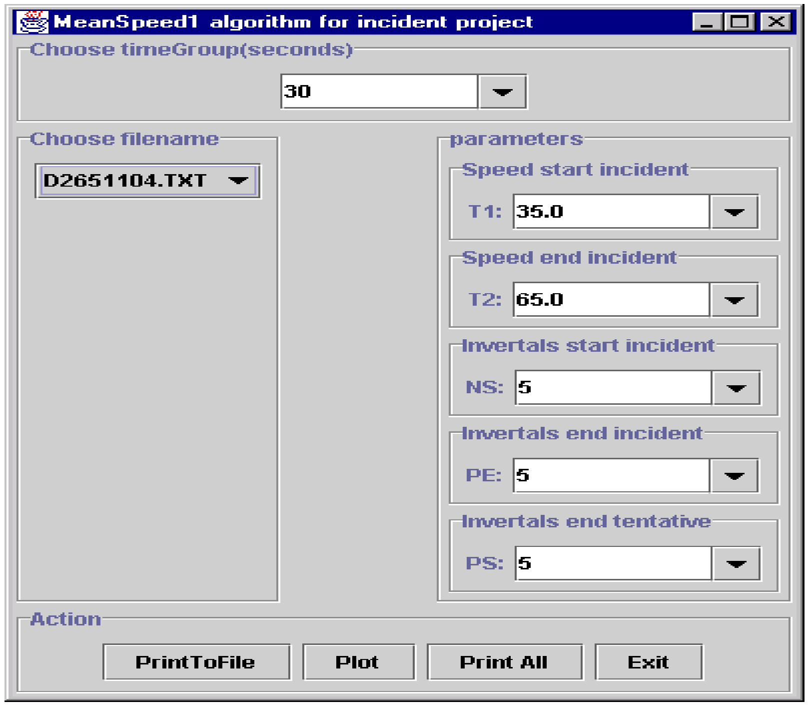

Figure 34. Mean Speed Transcore GUI

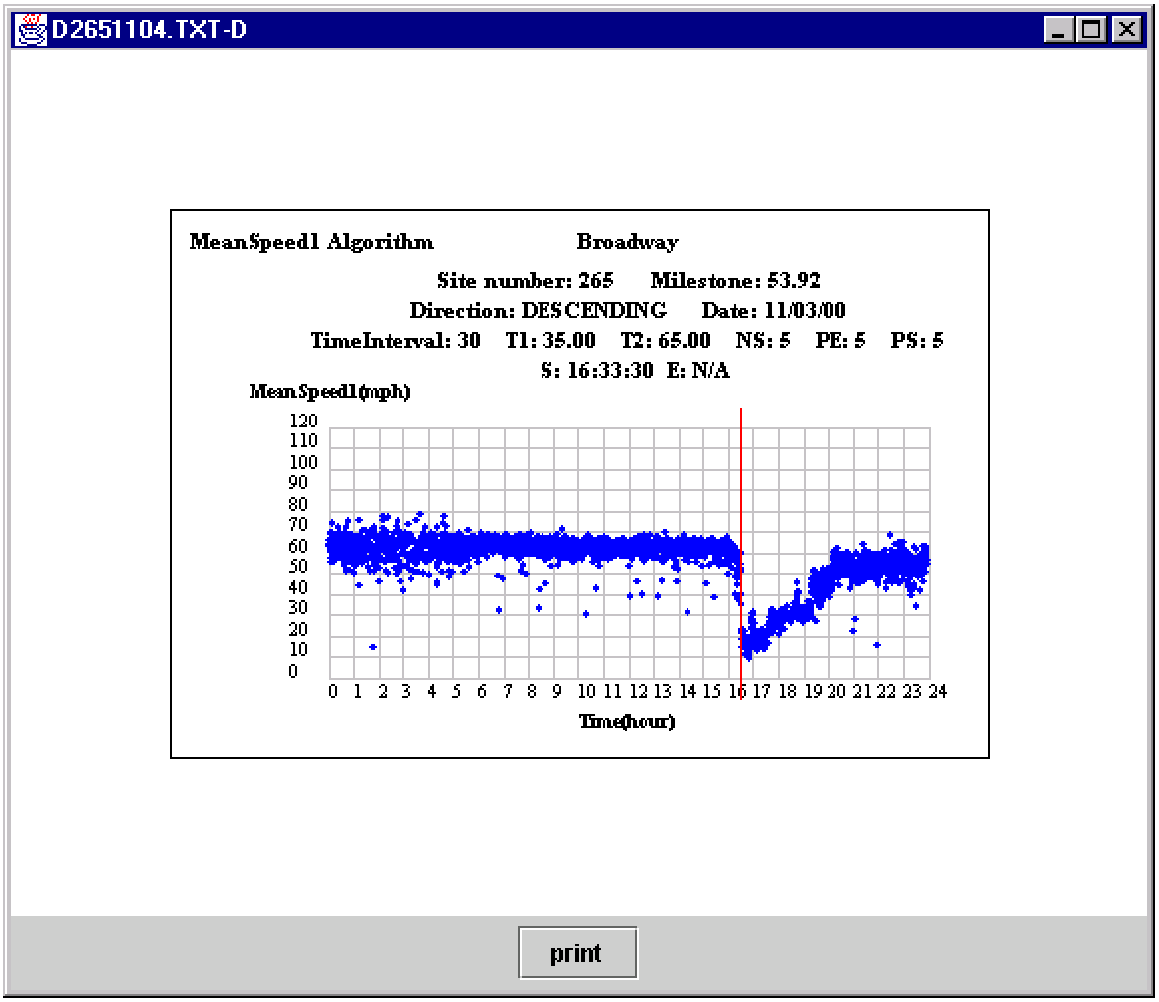

Figure 35. Mean Speed Transcore – Output

The graphical output from this program specifies the start and end time of the incident. From the incident response log, we know that an accident was reported at 5:15 PM in the Westbound direction on that date. The output shown above indicates an incident starting at about 4:30 PM. Perhaps the incident had already occurred before the ITD driver reached the scene. Also note that this particular algorithm is not able to declare the clearing of the incident that day. It should be kept in mind, however, that the result shown above is for the set of parameter values chosen for this particular run.

5.2.2 Mean Speed Algorithm – Modification 1

The user interface for the first modified algorithm is shown in Figure 36. As can be seen, there is one less parameter value that the user needs to choose for this algorithm.

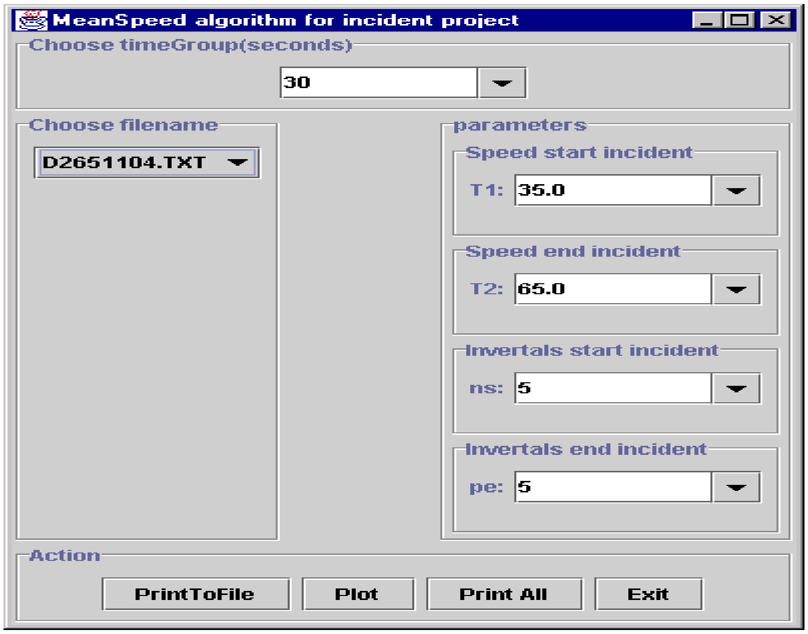

Figure 36. Mean Speed MOD 1 – GUI

The graphical output from running this program using data from the same location is shown in Figure 37. As with the Transcore algorithm, the end of the incident is also not identified for the particular values of the parameters chosen in this case.

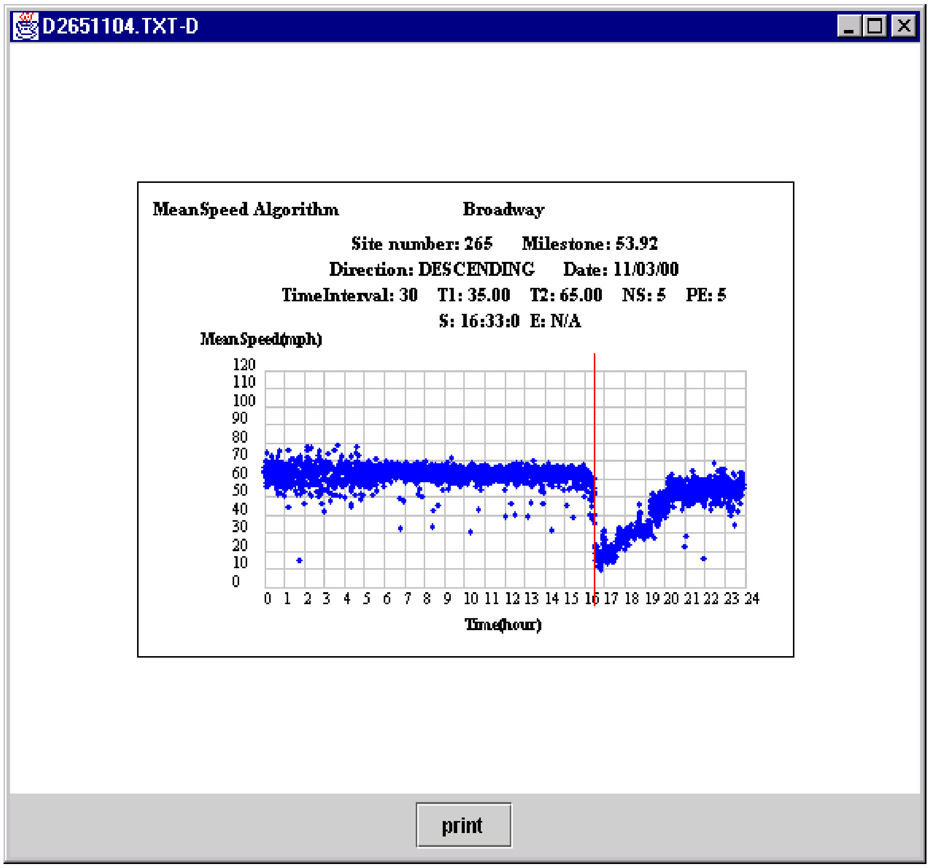

Figure 37. Mean Speed MOD 1 – Output

5.2.3 Mean Speed Algorithm – Modification Two

The GUI and Output screens from Modification Two are shown in Figures 38 and 39, respectively.

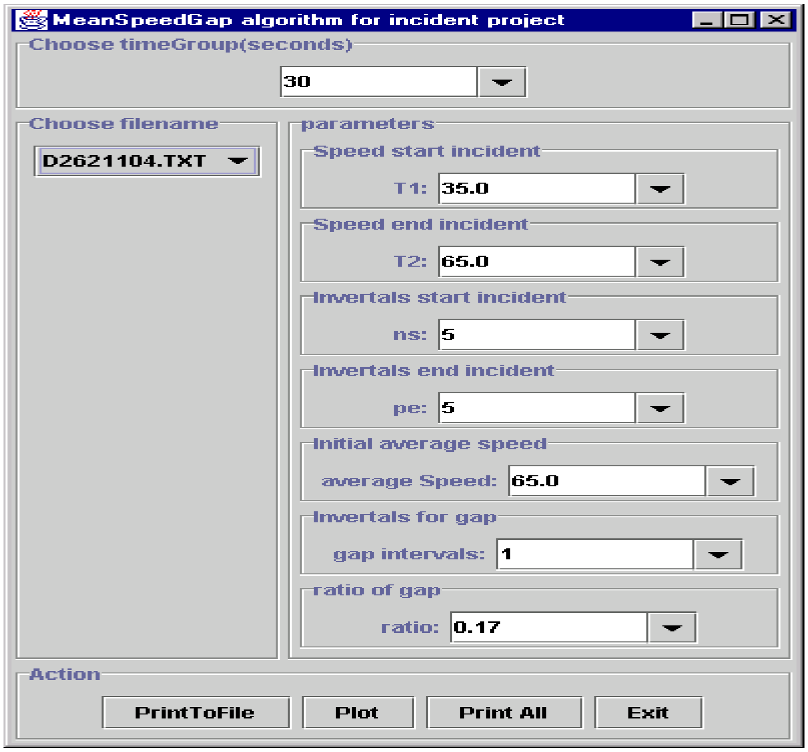

Figure 38. Mean Speed MOD 2 – GUI

Note that the user has to select more parameter values for this algorithm.

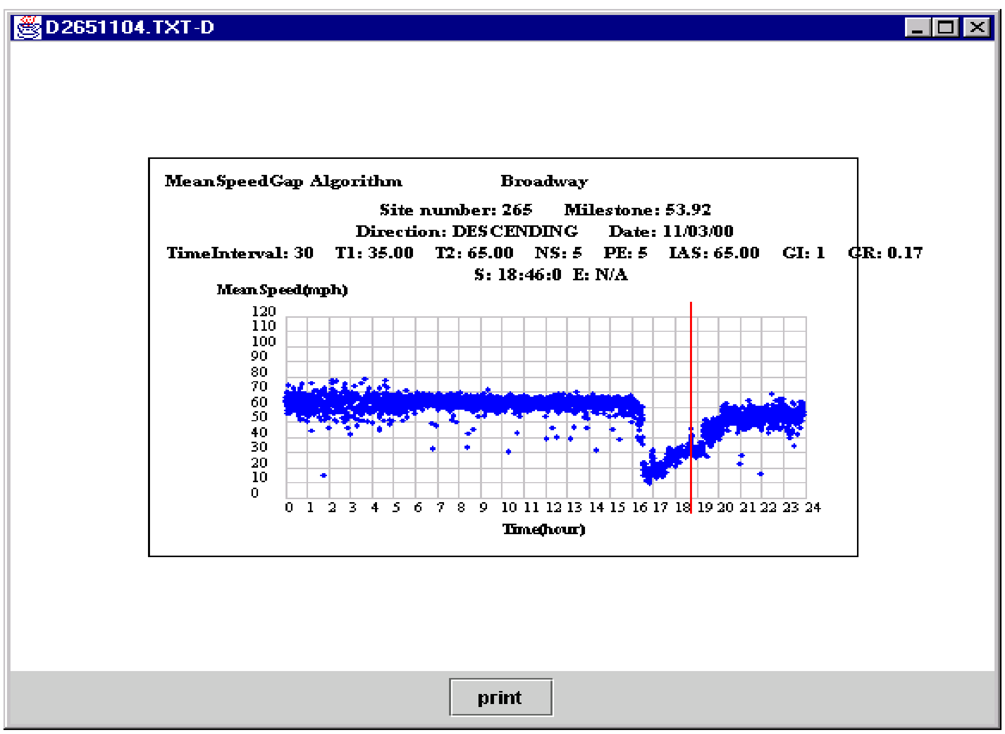

Figure 39. Mean Speed MOD 2 – Output

Modification Two of the mean speed algorithm is not able to identify the end of the incident either. In addition, the time it indicates as the start of the incident is also different from the times predicted by the previous two algorithms and by the incident response log.

5.2.4 Difference in Speed with Persistence Check Algorithm – Transcore

The difference in speed with persistence check algorithm obtained from Transcore is presented next. In the first dialog box the user selects the stations to use for the run, as shown in Figure 40.

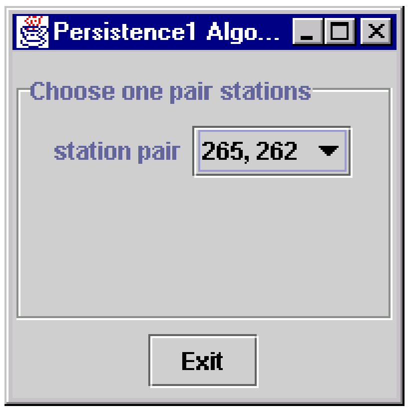

Figure 40. Difference in Speed TRANSCORE – GUI – 1

Then the parameter dialog box is displayed, as shown in Figure 41.

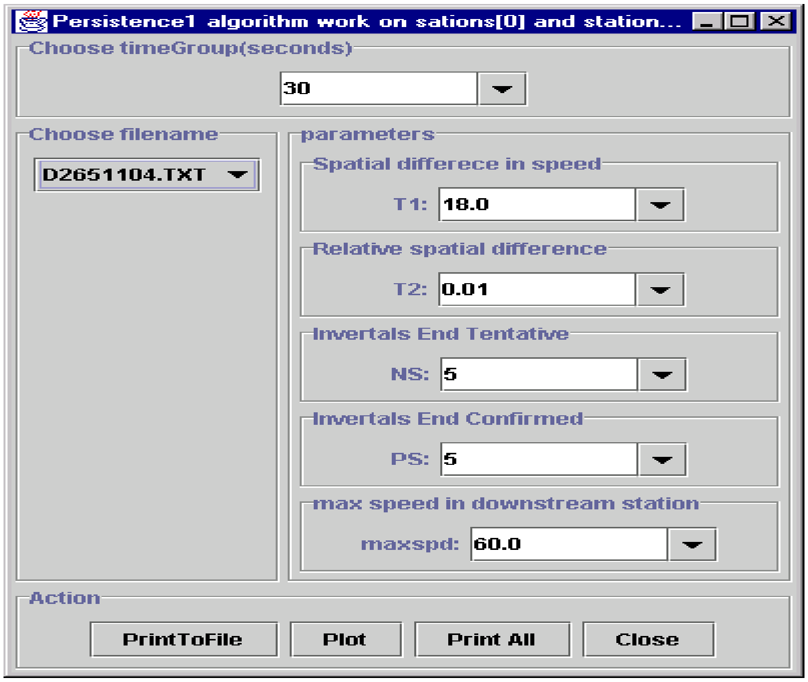

Figure 41. Difference in Speed Transcore – GUI – 2

The output from running this program is shown in Figure 42.

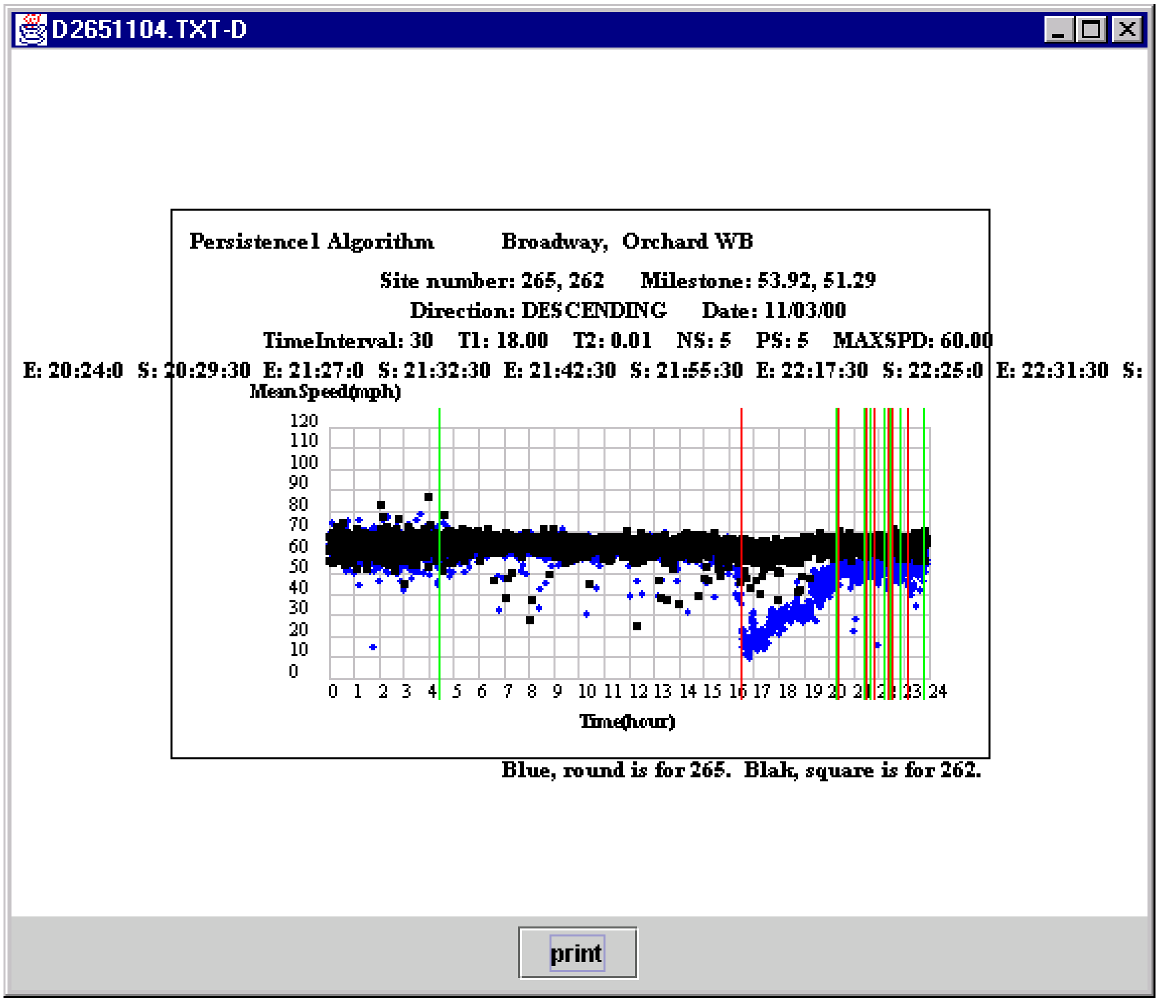

Figure 42. Difference in Speed Transcore – Output

As can be seen in the output, many entries and exits from incident conditions are identified by this algorithm for the set of parameter values selected for this run. It was observed that this behavior was influenced by the time aggregation that the user selected. The aggregation for the result shown above was 30 seconds. As this period was increased, the prediction of start and end of incidents became more reasonable.

5.2.5 Difference in Speed with Persistence Check Algorithm – Modification One

The output from the modified Difference-in-Speed algorithm is shown in Figure 43. There are two dialog boxes for this algorithm also, similar to the ones shown in Section 5.2.4. They are not shown here, as they do not have any additional information.

As can be seen in the figure, the simplified algorithm has only one pair of start and end times even for the 30-second time aggregation used.

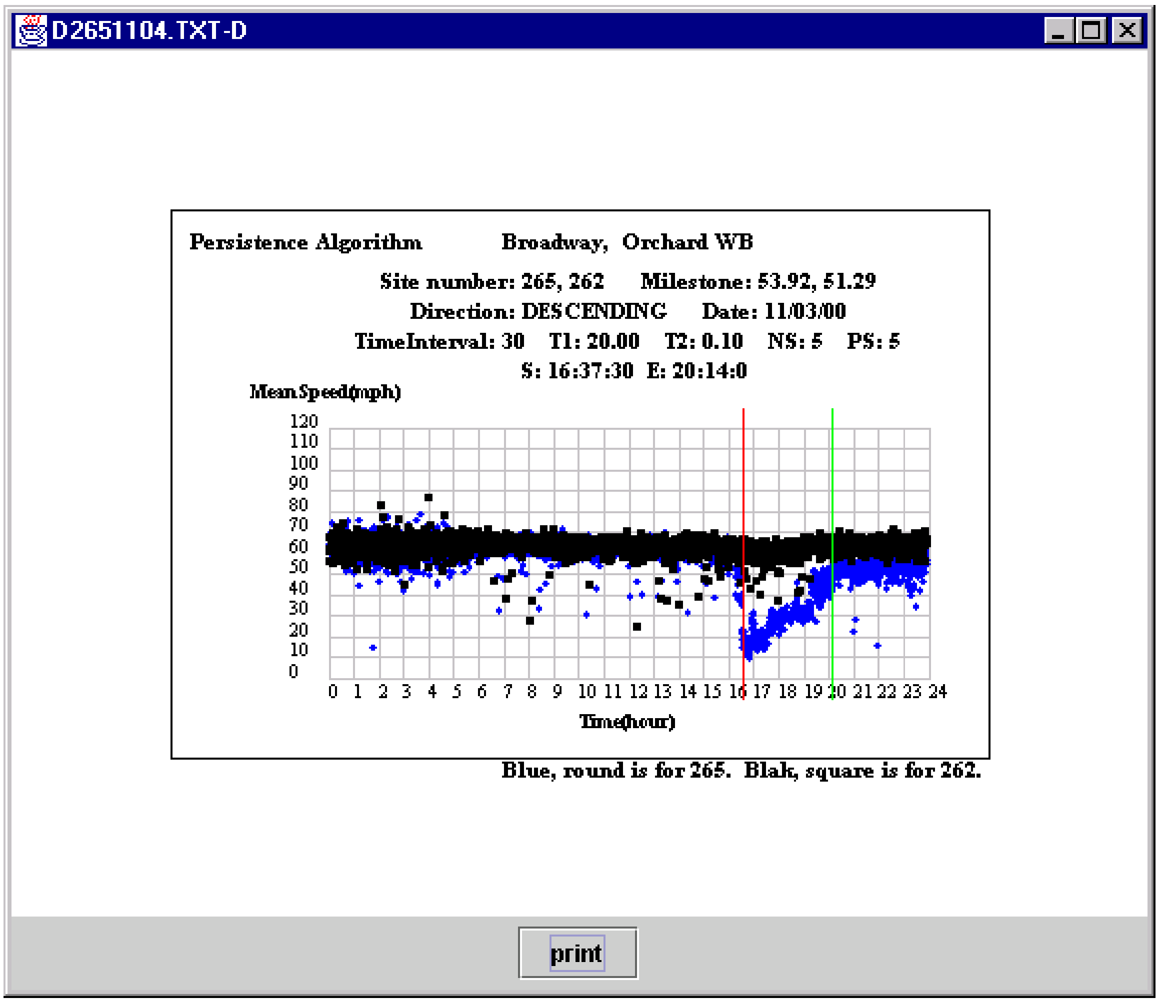

Figure 43. Difference in Speed Modification 1 – Output

5.2.6 California Algorithm #8

The final algorithm presented in this phase of the research, California Algorithm# 8, uses occupancy rather than the mean speed used by the other algorithms.

In the first dialog box, the user chooses the pair of stations to analyze, just as in the previous algorithm. The next dialog box is shown in Figure 44.

The time aggregation used in this case is 60 seconds, as this was the time used in early implementations in California. The set of parameter values used was obtained from the literature.

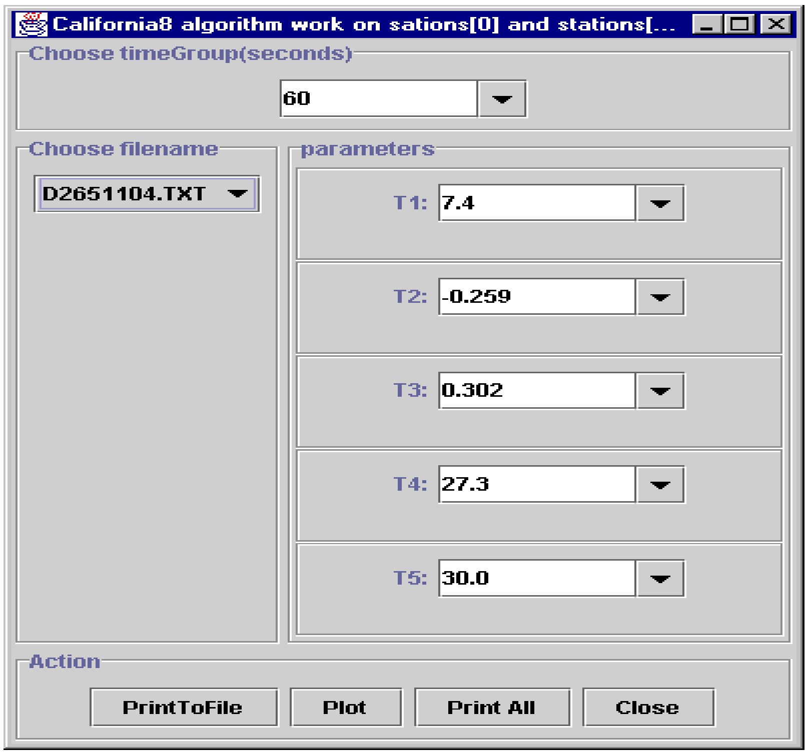

Figure 44. California Algorithm GUI

The output from running this algorithm with the set of values in Figure 44 is shown in Figure 45. And as can be seen in Figure 45, there are three pairs of start and end of incidents. More adjusting of the parameter values is needed for better understanding of the usefulness of this algorithm.

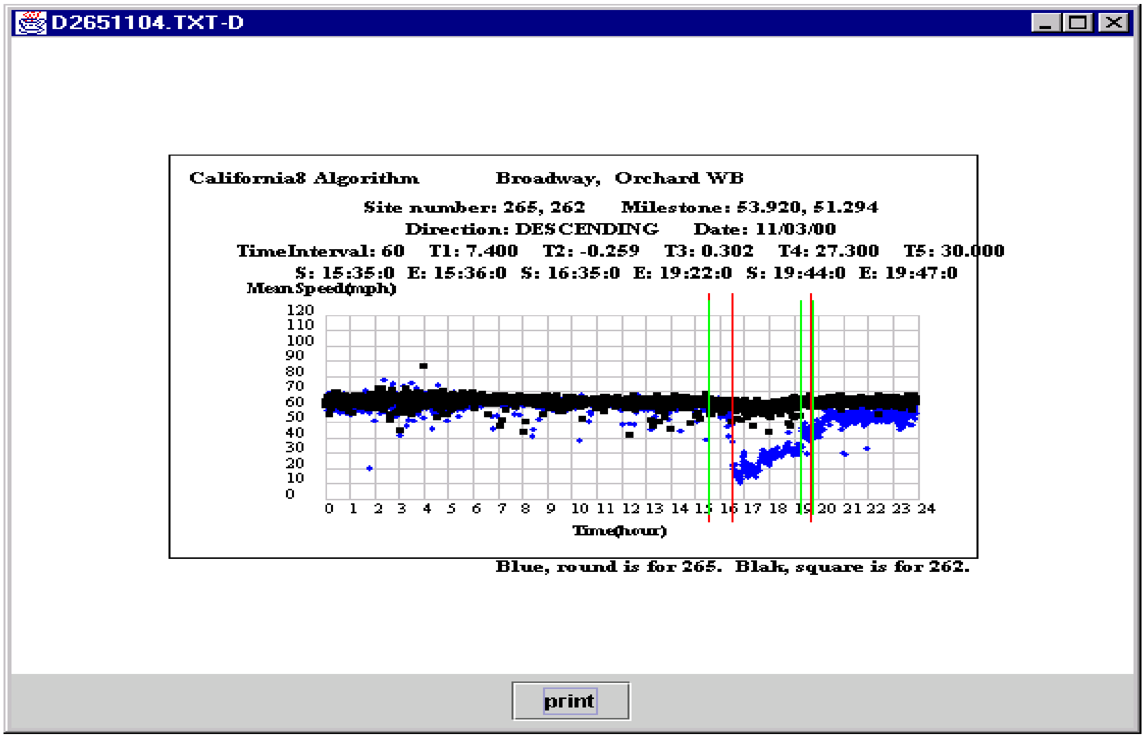

Figure 45. California Algorithm Output

6. TREASURE VALLEY INTEGRATED FREEWAY AND ARTERIAL SYSTEMS SIMULATION MODELS

6.1 Simulation Model Selection

In developing and testing different incident management plans in an integrated freeway and arterial system network, it is important to consider traffic operations on the arterial routes surrounding the affected portion of freeway as well as the freeway mainline itself. Several simulation models are available to conduct analyses of arterials or freeways, but few have the ability to model both simultaneously, taking into consideration the effects of one on the other. The TRAF family of models includes NETSIM and FRESIM, two microscopic models widely regarded as the most promising for use with arterials and freeways, respectively. The CORSIM simulation model combines these two models, allowing for a system-wide analysis of a freeway together with its surrounding arterial network.

When CORSIM models an integrated freeway and arterial street network, it models each of them in a separate subnetwork. However, the characteristics of vehicles and drivers (e.g., acceleration and deceleration rates and passive or aggressive tendencies) are carried through from one subnetwork to the next. This provides better replication of field conditions and a more accurate and reliable analysis. For example, a driver/vehicle combination designated as an aggressive driver in a high-performance sports car in one subnetwork will retain the same subcharacteristic in the other subnetwork. The traffic characteristics of one subnetwork are also reflected in the other subnetwork. For example, the queuing on ramps due to saturated conditions on the mainline are reflected in the arterial network as additional vehicles try to enter the ramp. Likewise, vehicles trying to exit the freeway onto a congested arterial will be forced to wait on the ramp or possibly even queue onto the mainline freeway until it is physically impossible for them to proceed.

The interaction of vehicles at the freeway/arterial interface is an important component of analyzing traffic conditions on an integrated freeway and arterial network.

CORSIM has the capability to model incidents on both the freeway and arterial streets in the coded network. This study is focused only on the effects of freeway incidents. Freeway incidents may take the form of complete lane blockages or merely slowdowns resulting from incidents or other activities taking place on the shoulder. The data required to specify the occurrence of an incident within a CORSIM dataset include the following:

- Link on which the incident occurs.
- Effect the incident has on each lane on the link, including any auxiliary lanes.
- Location of the incident along the link.
- Length of roadway affected by the incident.
- Time the incident occurs and how long it lasts.
- Rubberneck factor.
- Location of any signs warning of blockages.

In addition to the effects of incident blockage on traffic flow, CORSIM also models the rubbernecking phenomenon. The term rubbernecking refers to the tendency of drivers of vehicles in lanes adjacent to the incident to slow down as they pass the incident location. This reduction in speed results in lower lane throughput, and therefore lower lane capacity. This factor is what explains the additional capacity reduction, beyond that corresponding to the physical lane reduction that occurs as a result of an incident. For example, studies have shown that capacity reductions as a result of the blockage of one lane of a three-lane facility due to an incident are approximately 50%, rather than the 33% reduction one would expect from the 33% reduction in physical capacity.

CORSIM also allows user to specify the length of freeway blockage due to an incident. The FRESIM User Guide suggests that, "a reasonable estimate of the length of the blockage is the length of the number of vehicles involved plus one." Since the program uses an estimated length of 20 feet per vehicle, an incident involving two vehicles would be reasonably represented by a blockage of approximately 60 feet. However, for major incidents involving serious injuries or fatalities, the length of blockage should be extended far beyond these values to account for the presence of emergency vehicles and personnel.

In addition to this incident specification, the FREESIM manual suggests that a secondary incident consisting of only rubbernecking be placed at the upstream end of the primary incident. This secondary incident should be the same length as the primary incident and have the same duration. This would take into account drivers who begin to respond to an incident when they first see it, rather than waiting until they reach the physical location. The specification of an incident consisting of only rubbernecking can also be used to simulate the effects of an incident on the shoulder. In this case, no lanes on the freeway would be blocked by the incident, but capacity would be reduced due to the reduction in speed of drivers passing the incident.

Lanes at the incident location may be designated as fully blocked, having a capacity reduction caused by rubbernecking at the point of the incident, or flowing under normal conditions. For most lane-blocking incidents, the lanes not blocked by the incident will have some loss of capacity, as discussed earlier. This is modeled in CORSIM through the use of the rubberneck factor, which increases the distance at which vehicles follow each other.

The fact that COSRIM can reliably model freeway incidents, in addition to its ability to model integrated freeway and arterial system networks, made it the logical choice for this study. Traffic Software Integrated System (TSIS) version 4.32, developed by ITT Technology for the FHWA, was used in this project. TSIS represents the Windows shell application for CORSIM and other software that integrates with it.

Due to the relatively complex CORSIM input data process, a decision was made to use another program (Synchro 4.0) to build the network, and then transfer it to CORSIM. One major advantage of using Synchro to build the network is that it has a Windows-based, user-friendly data input interface, which meant that the entire arterial and surface street network could be built in a visually-based environment. Another advantage of using Synchro is its ability to import different CAD files as a background. Three Synchro files have been developed for the arterial and surface-street network from a MicroStation map of the Treasure Valley area.

6.2. Simulation Model Development

Once the determination was made to use CORSIM as the main simulation model for this project and Synchro to build the network, data acquisition efforts began to collect data required for the model development. The CORSIM network consists of nodes (intersections or interfaces between freeway and arterials) and links (arterials or freeways). The data required to build the model can be categorized into three main groups:

- Geometric configuration data (node coordinates, link lengths, number of lanes, lane configurations, etc.)
- Traffic characteristics data (traffic volumes, turning percentages, etc.)
- Traffic control data (type of intersection control, signal timing, signal coordination, etc.)

Figure 2, earlier in this report, presents the Treasure Valley Corridor network. The Treasure Valley corridor follows Interstate 84 from Milepost 25 to Milepost 60, through the cities of Caldwell, Nampa, Meridian, and Boise. This network covers the entire Boise metropolitan area. The study area consists of 211 intersections—93 signalized and 118 unsignalized. Of the 211 intersections, 142 are located in Ada County and the remaining 69 intersections are located in Canyon County. The arterial and surface street simulation model for the entire study area would consist of 650 nodes representing the 211 intersections, the entry/exit nodes, the interface nodes (the connection points between the freeway subnetwork and arterial system subnetwork), and the dummy nodes required by the model.

As the maximum number of nodes allowed in any CORSIM model cannot exceed 500 nodes, a determination was made to model the study area in three separate models. One network is located primarily in Canyon County, following I-84 from the interchange at Highwy 44 to Meridian Road. The second network runs from Meridian Rd. east into downtown Boise on I-184 and ends at the Orchard interchange on I-84. The third network runs from the Cole/Overland interchange southeast to interchange #60 at Federal Way.

Most of the data were obtained from two government agencies – ITD and ACHD. Some geometric and traffic data were obtained or verified through four on-site field data collection activities. Other sources of data included several agencies in the Treasure Valley area (Canyon County, City of Nampa, etc.), as well as transportation engineering firms that have conducted traffic studies within the area.

While it sounds as though it should be simple to obtain traffic data from these sources, it proved to be rather difficult. Some traffic data, especially traffic volumes on minor arterials and turning movement or signal timings at intersections, were either not available or they were 10 or 15 years old and only partially complete. Freeway traffic volumes were obtained through the ATRs counts. However, other freeway traffic data such as updated in/exit ramp volumes or freeway origin/destination data were not available.

Once the data collection activities provided enough information to build the models, three different Synchro files were developed. All the traffic and geometric data were input into the Synchro files, and then the files were converted into CORSIM files. Figures 46 through 49 show the three simulation models for the Treasure Valley area in Synchro and CORSIM formats.

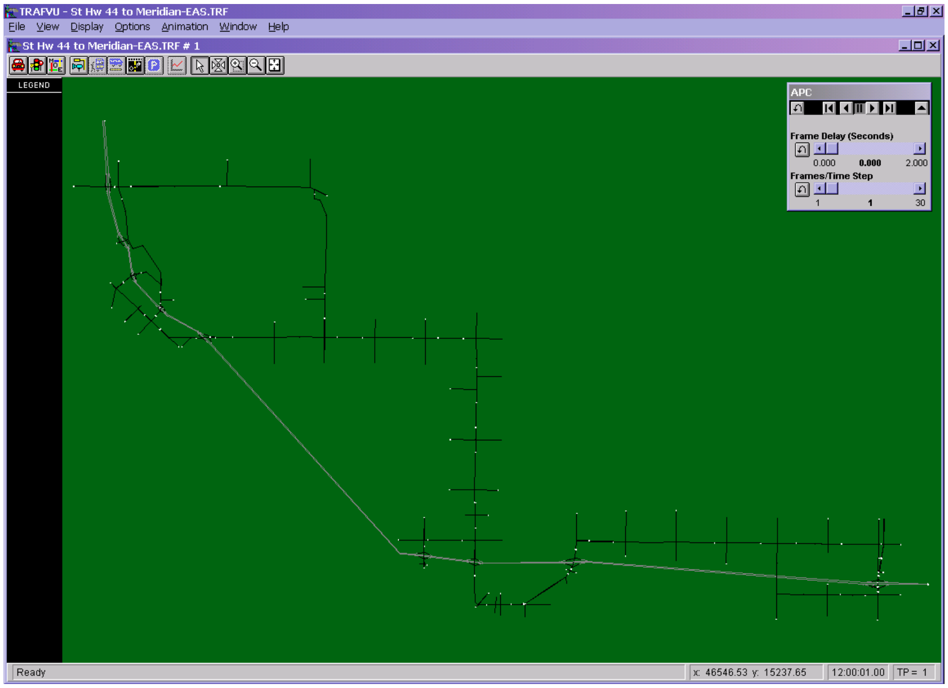

Figure 46. The CORSIM Simulation Model for Canyon County

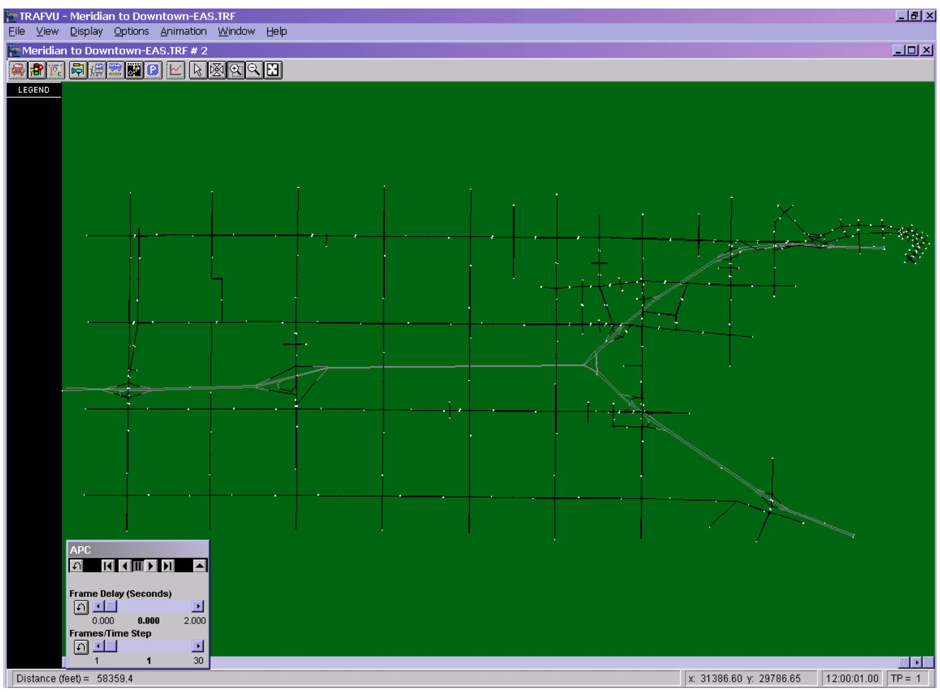

Figure 47. The CORSIM Simulation Model for Ada County

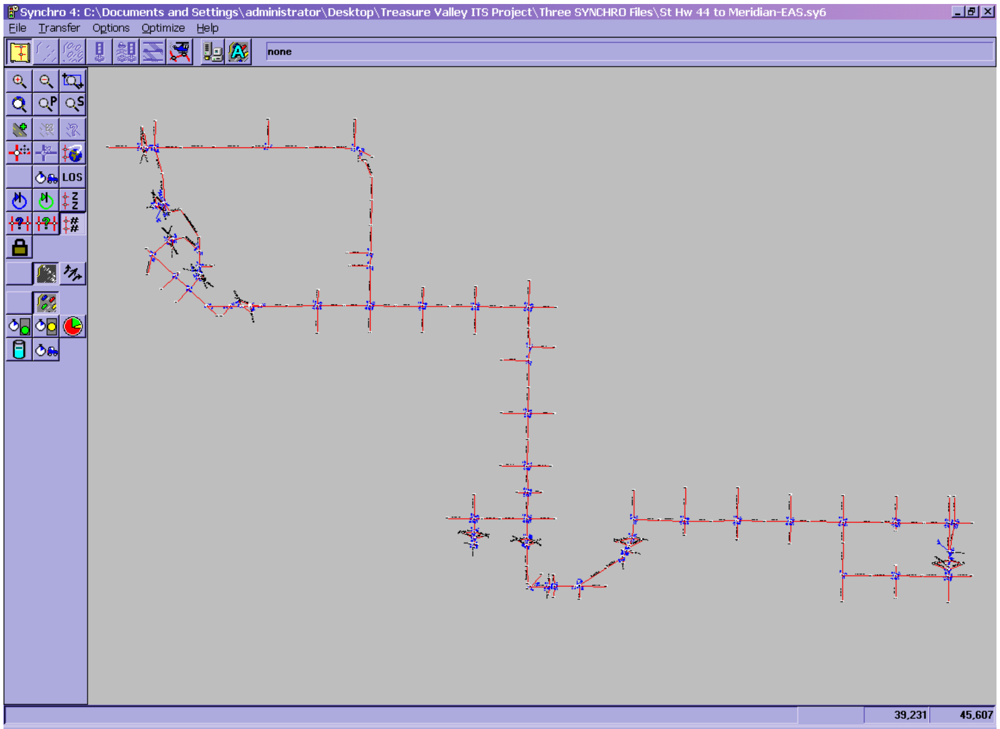

Figure 48. The SYNCHRO Model for Canyon County

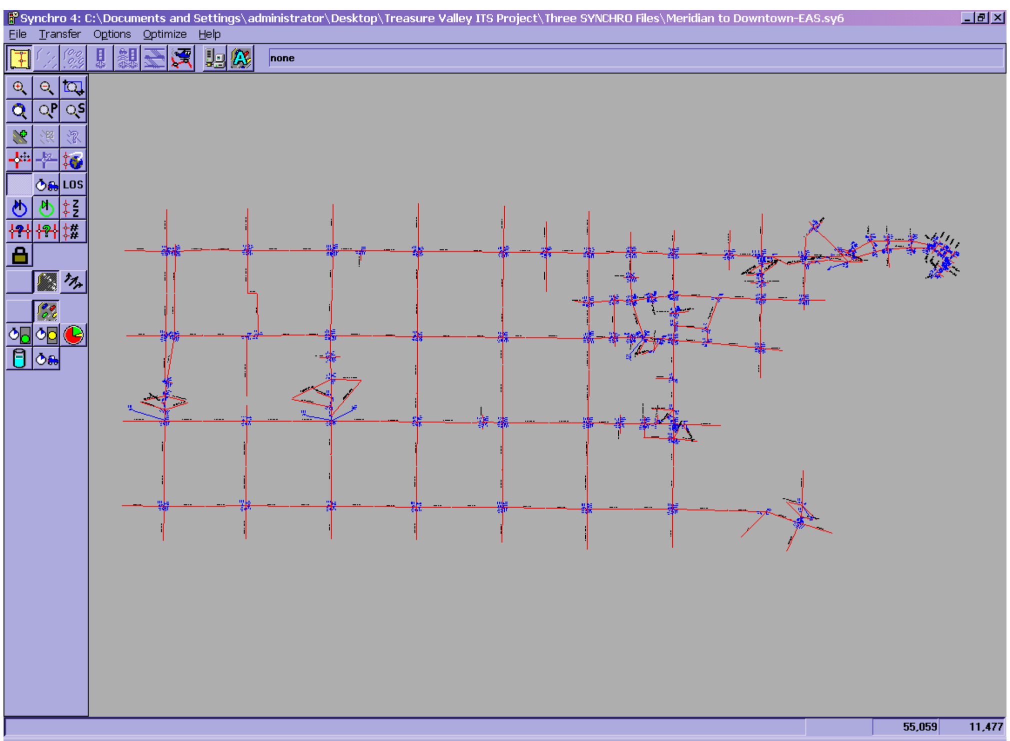

Figure 49. The SYNCHRO Model for Ada County

6.3 Calibration and Validation of the Simulation Models

The CORSIM simulation model is built upon a basic set of stochastic algorithms that attempt to represent vehicular traffic flow through various types of roadway systems under various conditions. Because of the stochastic nature of simulation programs, their use requires that two basic steps be completed prior to finalizing any analysis results. First, traffic flow characteristics and driver behavior components of the model need to be calibrated to conditions observed or measured in the field. Second, the calibration needs to be linked directly to validation of the model, involving a comparison of simulated and observed traffic flow conditions of the system under study. This comparison is intended to provide a direct measurement of how well the model results match the existing and observed traffic flow conditions.

Calibration of the simulation model is the process by which the individual components of the simulation model are adjusted or tuned so that the model will accurately represent field-measured or observed traffic conditions. The unique components or parameters of a simulation model that require calibration include the traffic flow characteristics and driver behavior. CORSIM and other simulation models contain numerous variables to describe traffic flow characteristics and driver behavior. Simulation models contain default values for each variable, but also allow a range of user-supplied values for each variable. In some cases, the variables affect the entire network while others are specific to individual roadway segments or nodes. Changes to these variables during calibration should be based on field-measured or observed conditions.

While there was enough data provided by the ATRs to calibrate the freeway simulation model, not as much data were available to calibrate the arterial system network. Several traffic flow and driver behavior characteristics in the model, such as free-flow speed, the percentage of trucks in traffic, and the percentage of different driver types, were input to the model based on the actual values obtained from the ATRs data.

To calibrate and validate the freeway models, detectors were placed on the freeway and the average detector occupancy was used as the main calibration factor. Traffic volumes for the freeway were chosen to match those reported by the ATR stations. Driver behavior characteristics, such as car-following sensitivity factors and percent of different driver types in the traffic were adjusted to reflect the conditions in the field. The difference between the average detector occupancy in CORSIM and in the field ranged from 3% to 11%, with an average value of 7.3%. This relatively low error indicates that the freeway simulation models are validated and can reliably represent the actual traffic conditions in the field.

As mentioned before, there were not enough data available to carry out a comprehensive calibration and validation analysis for the arterial system simulation models. The only data available were throughput data (average hourly volumes) for some intersections on the diversion routes, reported in the Interstate Diversion Route Study conducted by Six Mile Engineering and Transcore for ACHD. These traffic volumes were used for calibrating the arterial systems simulation models for both Ada and Canyon Counties. The difference between the simulated and field volumes ranged from 4% to 19%, with an average of 11.2%. Considering the size of the network and the quality of the traffic and turning movement data available, this relatively high error rate seems tolerable, and the simulation models can be used in the analysis with a high degree of confidence. More validation analyses are required and will be part of Phase II activities for this project.

7. SIMULATION MODELS - INITIAL ANALYSIS AND RESULTS

7.1 Analysis

The validated simulation models were used to conduct comparative analysis to determine the effectiveness and potential benefits of the proposed diversion route plans for the Treasure Valley Corridor. It should be noted here that the analysis presented in this report is only a preliminary analysis. Its purpose is to illustrate the effectiveness of the simulation models developed in this phase of the project and their potential use in developing and testing different incident management plans. Phase II of this project will include a more detailed analysis using these simulation models.

The objective of this comparative analysis was to examine and quantify the potential system-wide delay reduction benefits that might be achieved by deploying the integrated incident management system in the Treasure Valley area. The analysis examined how effective the freeway diversion plans would be at reducing the area-wide delay for both the freeway and arterial systems networks. A case study consisting of 10 actual incidents that occurred during the afternoon peak period was chosen for the analysis. These incidents were selected from the 48 incidents that occurred on I-84 from September 11, 2000 to February 28, 2001. A list of the incidents and their characteristics are presented in Table 8.

Table 8. Characteristics of Incidents Examined in the Analysis

Incident	Location	Time	Type of Incident	Duration (minutes)	No. Of Lanes	
					Total	Closed
1	MP 48 EB	8:54	2-vehicle accident, No Injury	14	2	1
2	MP 58 EB	17:45	2-vehicle accident, No Injury	17	2	1
3	MP 49 EB	16:03	2-vehicle accident, No Injury	15	2	2
4	MP 49 EB	16:47	2-vehicle accident, No Injury	19	3	2
5	MP 51 WB	8:54	2-vehicle accident, Injuries	22	2	2
6	MP 52 WB	16:45	2-vehicle accident, No Injury	26	2	2
7	MP 54 EB	8:44	2-vehicle accident, Injury	31	3	3
8	MP 48 WB	17:35	3-vehicle accident, Injuries	36	3	3
9	MP 48 EB	18:47	Semi truck-slide off the road	54	3	3
10	MP 48 EB	8:54	Semi truck accident	61	3	3

The incidents were modeled in the CORSIM simulation models. Freeway volumes were adjusted to reflect the actual traffic volumes during the incident time. The traffic volumes in the arterial systems were kept constant and represented the traffic volumes in the network during the afternoon peak period. For all five incidents, the freeway was assumed to be fully blocked during the entire duration of the incident. The incidents were first modeled with NO-ACTION taken. This means that the freeway traffic stayed on the freeway during the entire incident duration. Once the incident was removed, the queue resulting from the incident began to dissipate until traffic on the freeway returned to its normal condition. For each of the incidents, the total freeway subnetwork delay, total arterial systems subnetwork delay, and time for freeway traffic to return to its normal condition were recorded.

The next step in the analysis was to model the same incidents; with the freeway diversion route plans being deployed. It was assumed that five minutes after the incident occurred all freeway traffic would be diverted from the exit ramp upstream from the incident location to the arterial systems network. The five-minute period was intended to account for the time it takes the TMC to deploy the diversion route plans. The cycle length for the signalized intersections along the diversion routes was varied from 140 to 180 seconds in 10 second increments, to accommodate the diverted freeway traffic and increase the throughput of the arterial systems. The diversion of freeway traffic would stop 5 minutes prior to the incident clearance time. Again, the total freeway subnetwork delay, total arterial systems subnetwork delay, and time for freeway traffic to return to its normal conditions were recorded and compared with the values obtained from the first step of the analysis.

7.2 Results

Results from the simulation model analyses are presented in Tables 9 and 10 for the 10 incidents examined in this study. Table 9 presents network-wide Total Travel Time (TTT) in vehicle-hours with and without freeway diversion route plans. Table 10 presents the relative percent reduction in network-wide TTT, defined as:

$$P_i = \left(\frac{TTT_{DoNothing} - TTT_{Diversion}}{TTT_{DoNothing} - TTT_{NoIncident}} \right)$$

Where:

P_i	is the performance measure for diversion plan i
$TTT_{DoNothing}$	is the network-wide total travel time under the incident with no diversion plans
$TTT_{Diversion}$	is the network-wide total travel time under the incident with diversion plans
$TTT_{NoIncident}$	is the network-wide total travel time under no incident

The reduction in area-wide delay as a result of implementing the freeway diversion route plans ranged from 13.9% to 27.2%. The freeway subnetwork total delay decreased, on average, by 76.4%, whereas the delay for the arterial system subnetwork increased, on average, by 61.3%.

Five signal-timing plans with cycle lengths ranging from 140 seconds to 180 seconds were considered in this study. The signal timing plans for the coordinated actuated signals along the diversions routes were optimized off-line based on average volume during different time periods. Offsets were optimized to provide maximum throughput for the freeway traffic diverted to the corridor. The results show that the relative percent reduction of TTT as a result of implementing the freeway diversion routes is much higher for incidents that have moderate severity and/or duration. The percent reduction in TTT for severe incidents was much lower, mainly due to the limited capacity of the Treasure Valley's diversion routes. The benefit of using real-time operational characteristics in the evaluation seems also to be greater for incidents of moderate severity and duration. The results indicated that the integrated simulation model can be used successfully in evaluating different diversion route alternatives and identifying the optimal alternative among them. The use of real-time demand and vehicle-mix data in the integrated microscopic simulation model allowed for a more accurate estimation of the expected benefit of the proposed diversion alternatives.

Table 9. Network-Wide Total Travel Time (Vehicle-Hours) Under Different Signal Timing Plans

Incident	Duration	TTT (No Incident)	TTT (Do Nothing)	Cycle length for the signal timing plan				
				CL=140	CL=150	CL=160	CL=170	CL=180
1	14	5388	5701	5423	5421	5409	5436	5506
2	17	5657	5881	5726	5714	5696	5709	5720
3	15	4957	5727	5311	5304	5321	5335	5328
4	19	6196	7410	6718	6694	6653	6648	6631
5	22	5550	6810	6158	6151	6148	6123	6109
6	26	6196	7870	7211	7188	7164	7166	7179
7	31	5280	7001	6119	6088	6080	6071	6089
8	36	6466	8949	8112	8089	8061	8042	8009
9	54	4634	7487	6844	6832	6829	6811	6799
10	61	5388	9246	8321	8309	8298	8276	8244

Table 10. Relative Percent Reduction in Network-Wide Total Travel Time (P_i)

Incident	Duration	P_i for different signal timing plans				
		CL=140	CL=150	CL=160	CL=170	CL=180
1	14	0.888	0.895	**0.933**	0.847	0.623
2	17	0.693	0.747	**0.827**	0.769	0.720
3	15	0.540	**0.550**	0.527	0.509	0.518
4	19	0.570	0.590	0.624	0.628	**0.642**
5	22	0.517	0.523	0.525	0.545	**0.556**
6	26	0.394	0.407	**0.422**	0.420	0.413
7	31	0.513	0.531	0.535	0.540	**0.530**
8	36	0.337	0.346	0.358	0.365	**0.379**
9	54	0.225	0.230	0.231	0.237	**0.241**
10	61	0.240	0.243	0.246	0.252	**0.260**

8. SUMMARY

During Phase I of the project, the following were accomplished:

- Freeway data were collected and used to analyze the freeway operation and incident characteristics for the corridor. The results show that the freeway corridor operates under stable free-flow conditions with volume/capacity ratios ranging from 0.42 to 0.72.
- The software was developed for analyzing the freeway data and testing the AID algorithms. Six algorithms were evaluated and tested using the Treasure Valley freeway data and the output from these algorithms is presented in this report. One of the goals of this research was to recommend the most suitable algorithm for use by ITD. This goal has not been achieved yet. The parameter values of the six algorithms will need to be further examined and a new set of values will need to be developed and tested.
- Three simulation models for the Treasure Valley corridor were developed, calibrated and validated. The models were used to analyze the freeway operation during incident situations with and without incident management and diversion route plans. A preliminary analysis of the Treasure Valley IMP was conducted using these models. The results of the analysis show that the reduction in area-wide delay as a result of implementing the freeway diversion route plans can range from 13.9% to 27.2%. The freeway subnetwork total delay decreased, on average, by 76.4%, whereas the delay for the arterial system subnetwork increased, on average, by 61.3%. More detailed analysis to develop signal control strategies for the arterial systems and to examine different incident management plans will be conducted in Phase II of this project

9. PROPOSED PHASE II ACTIVITIES

In Phase II of this project, the following activities are proposed:

1) The parameter values of the six algorithms will be further examined and a new set of values will be developed and tested. After the parameter values are adjusted to reflect site-specific characteristics, recommendations can be made for the use of a particular algorithm or group of algorithms in the I-84 corridor. It is also proposed that some additional algorithms be implemented in Phase II. One is the McMaster algorithm. Others can also be examined depending on the needs of ITD and the Ada County Highway District.

2) Signal control plans will be developed and tested for the actuated controllers located on the arterial system networks in the proposed diversion route plans.

3) Phase II will also include the development of a set of materials and facilities that can be used to train practicing professionals and students in managing freeway incidents and TMC operations. A Virtual Traffic Management Center (VTMC) will be established at the University of Idaho in Moscow and at Boise State University in Boise. Using real-time freeway data and the simulation models developed for this project, the VTMC will be used to train TMC operators to manage incidents under a variety of freeway operational conditions.