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An Analysis of CMS Impact on Incident-Based Congestion

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In-Kyu Lim

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AN ANALYSIS OF CMS IMPACT ON INCIDENT-BASED CONGESTION

By

In-Kyu Lim

A DISSERTATION

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ABSTRACT

AN ANALYSIS OF CMS IMPACT ON INCIDENT-BASED CONGESTION

By

In-Kyu Lim

Changeable Message Signs (CMS) are the most visible traffic control devices that provide real-time traffic information about downstream congestion or potential delays to drivers. Their use is intended to modify roadway travel choices through en-route diversion. A high route diversion rate can reduce severe congestion, improve safety, and network performance. However, given the same information, each of the CMS deployment locations are not likely to produce the same level of effectiveness. Under various conditions, based on human, traffic, and geographic characteristics, the CMS vary in their effectiveness. Evaluation of CMS system performance using observed field data was not strenuously researched in previous studies, and no studies have evaluated their effectiveness under various conditions.

To analyze the effectiveness of CMS as it pertains to drivers' route diversion behavior, this study measures the percentage of traffic that diverts to an alternate route during the time the CMS displays a message based on empirical field traffic data under various conditions. A method to estimate travel time from upstream to downstream location using the discrete Inductive Loop Detector (ILD) traffic data was developed an implemented. The sensitivity of the diversion to four different factors: visual observation, familiarity and time constraints, historical or existing traffic conditions, and geographic location were also tested.

Dedicated to my parents,

Won-Uong Lim and Hyun-Sook Han

and

Kyung-Koo Lee and Hyo-Soon Ra

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CHAPTER 1

INTRODUCTION

1.1 Introduction

As population increases, so too does the demand for greater highway capacity. This is particularly true in metropolitan areas, and construction of new highways to accommodate this demand has not increased proportionally to population growth. Between 1980 and 1999, route miles of highways in the United States increased only 1.5 percent while vehicle miles of travel increased 76 percent (FHWA, 1998). The Texas Transportation Institute (TTI) reports that the average annual delay per person in the 75 largest urban areas increased from 7 hours to 26 hours between 1982 and 2001. The measurable, primary costs of congestion in 2001 totaled $69.5 billion: the monetary impact of 3.5 billion hours of delay and 5.7 billion gallons of excess fuel consumed. These combined costs have contributed to traffic congestion being recognized as one of the most significant problems in urban areas.

Traffic congestion is classified into two groups: recurring and non-recurring, based on the primary cause(s) at any given period of time when occupancy exceeds capacity. Recurring congestion can be defined as that which routinely appears during certain peak-hour periods of excessive traffic demand. The most distinctive feature of recurring congestion is that it occurs virtually every week day, and at the same location. Therefore, this congestion is sometimes referred as "expected congestion". "Non-recurring congestion" is caused by unexpected events including traffic incidents (for purposes of this paper, the term "traffic incidents" refers to any incident which is sudden, occurs randomly, and affects the normal flow of traffic, e.g., accidents, stalled vehicles, etc.), construction on or adjacent to the roadway, severe weather and sudden volume increases from special events. A number of recent studies show that less than half of the congestion experienced by drivers in the US is caused by recurring congestion. Slightly more than half is caused by non-recurring congestion. Non-recurring congestion dramatically reduces the available capacity and reliability of the transportation system, and travelers are especially sensitive to these unanticipated or unexpected disruptions in their personal activity.

The Federal Highway Administration (FHWA) is focusing their efforts to mitigate traffic congestion problems through several congestion improvement programs. As part of these programs, they are helping state and local transportation partners develop regional frameworks for the integrated development of Intelligent Transportation Systems (ITS) technology, computerized traffic control systems, traveler information systems, and public transit information management systems. The Advanced Traveler Information System (ATIS) is one of the most-widely used components of Intelligent Transportation Systems (ITS).

1.2 Advanced Traveler Information Systems (ATIS)

The ATIS includes Changeable Message Signs (CMS), route guidance, telephone information, and commercial radio systems, Highway Advisory Radio (HAR), and personal communication devices such as pagers, the Internet, and designated telephone numbers (e.g., 511). The ATIS assist motorists in making more-informed decisions on congestion avoidance by their pre-route and en-route path selection. This system plays a pivotal role in reducing traffic congestion, improving safety, enhancing mobility, and improving energy efficiency, which, in turn, reduces environmental pollution.

1.3 ATIS Characteristics

The ATIS provide static and/or real-time traffic information. Static information includes planned road construction and maintenance, special events, tolls and payment options, and transit schedules and fares. Static systems provide information on long term events such as construction activities or road closures. Real-time systems provide minute-by-minute information on roadway conditions including congestion and incidents. It may also convey information on available alternate routes, travel time to a destination based on time of day, transit bus schedules and the availability of spaces in parking lots. This real-time information is frequently updated in response to current conditions and is useful in pre-trip and/or en-route traveler decisions. Travelers have repeatedly affirmed the efficacy of real-time information, stating that it is the most helpful in providing the information they need to make decisions about their route choice.

Pre-trip traveler information may include road and weather conditions, a business directory (i.e., tourist attractions, hotels, and restaurants), various routes to a chosen destination, and typical travel time. En-route traveler information provides traffic information including congestion, incidents, construction zones, weather conditions and recommended safe speeds. Figure 1.1 presents the generic ATIS system showing how information on current conditions is gathered and dispersed through different control devices (Schiesel and Demetsky 2000).

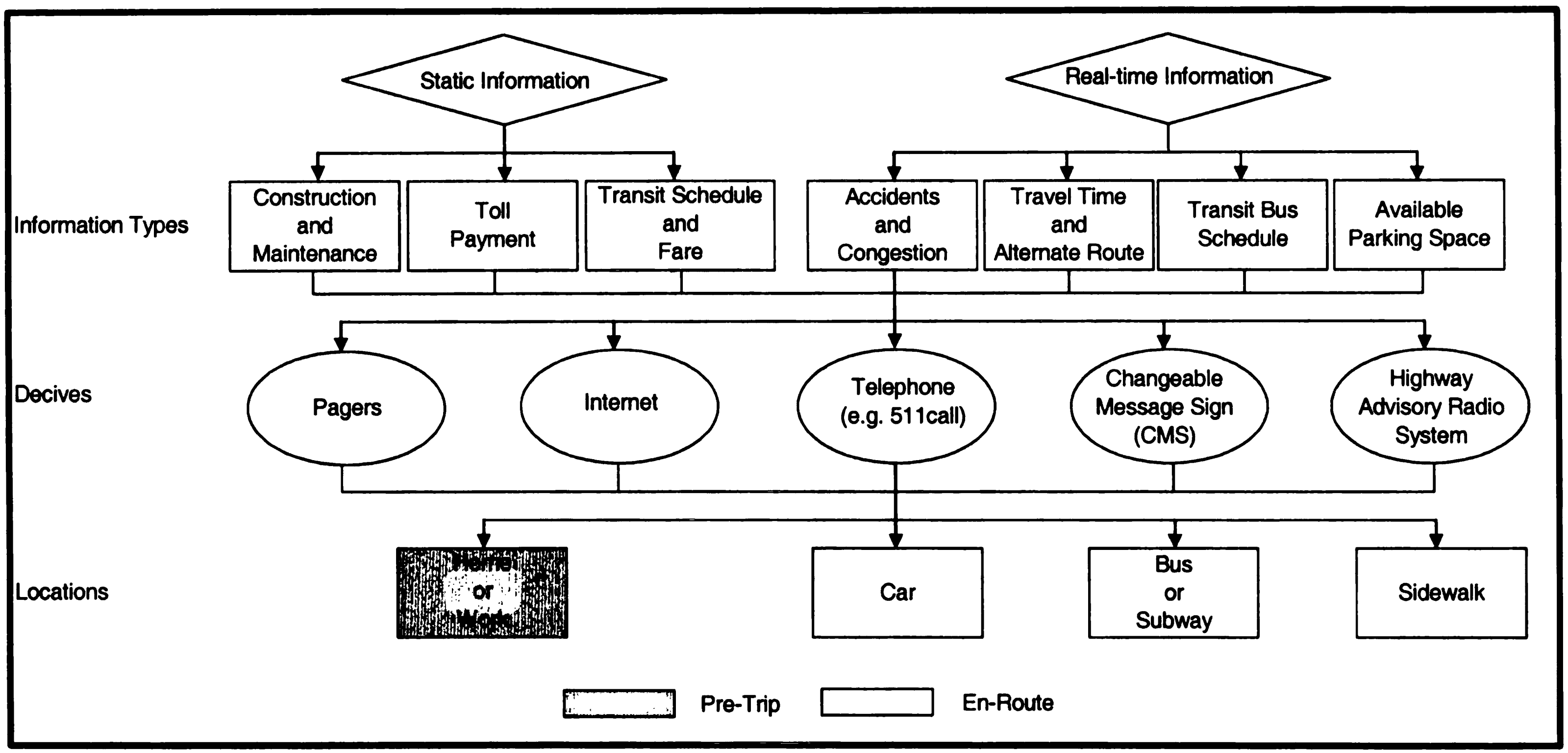


Figure 1. 1 Generic ATIS System (Schiesel and Demetsky 2000)

1.3.1 ATIS Benefits

Advanced Traveler Information Systems (ATIS) are intended to provide traffic information that is timely, accurate and reliable to help people make more informed travel decision. The following list shows the benefits from using ATIS as reported by the U.S. Department of Transportation (Mitretek, 1997).

- Reduced travel time (4-20%, more in severe congestion)
- Decreased traveler stress
- Decreased crash risk (4-10%) and fatalities (e.g., reduced driver distractions on unfamiliar routes)
- Enhanced ability to avoid unexpected congestion
- Decreased energy consumption and air pollution (decreased HC emissions by 16-25% and CO emission by 7-33%)
- Promotes other travel modes
- Reduced inter-modal travel times

1.3.2 ATIS Performance Measures

An ATIS performance evaluation aids in understanding how well the system is performing with regard to its intended objectives, and how it is likely to perform in the future given anticipated circumstances. This can help determine whether or not an applied system was appropriate, identify potential problems, and provide guidance for solutions. Several Measures of Effectiveness (MOEs) have been used to evaluate the performance of ATIS, and different MOEs are used depending on the type of data collected and the purpose of the evaluation. The following describes some of the performance measures used in prior studies classified by purpose.

Operational Effectiveness Measures

- Increased volume to capacity (v/c) ratio
- Decreased average congestion delay
- Increased average traffic speed or decreased average travel time
- Decreased number or percentage of stops

Environmental Effectiveness Measures

- Vehicle emission reduction
- NO_x reduction
- CO and $(CO)_x$ reduction

Economic Effectiveness Measures

- Travel or delay time savings
- Fuel savings
- Reduction of monetary costs associated with vehicle accidents

System Effectiveness Measures

- Decreased average travel time
- Increased Vehicle Miles of Travel (VMT) or Person Miles of Travel (PMT) per unit time

- Improved level of service (LOS)
- Reduced lost time or delay

1.4 Description of Research Area

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) established the national Intelligent Vehicle Highway System (IVHS) program (now known as the Intelligent Transportation Systems (ITS)). The program was designed to promote the use of advanced transportation technologies in the United States. In 1995, the Michigan Department of Transportation (MDOT) initiated the process of designing and building the ITS infrastructure in southeast Michigan. It was the largest ITS deployment and traffic monitoring system in the world at that time. The system consists of 180 total freeway miles including selected segments of I-96, I-94, I-75, M-39, M-10 and the I-696/I-275 circumferential freeway, in the metropolitan Detroit area. The system included 59 CMS locations, 156 closed-circuit television (CCTV) cameras, 61 ramp meters, 2260 Inductive Loop Detectors (ILD), and 11 Highway Advisory Radio (HAR) transmitters.

The Michigan Intelligent Transportation Systems Center, known as the "MITS Center," in cooperation with the Michigan Department of Transportation (MDOT), provides motorists with real-time traffic information via the Changeable Message Signs (CMS). The CMS conveys highway traffic information to drivers and alerts them to sudden or unexpected changes in traffic conditions. This information includes accidents, disabled vehicles, construction, road maintenance activities, and severe weather. All messages inform drivers of what has caused or will cause the upcoming change in travel conditions (reason message posted), the location of the change, and what effect it will have on traffic conditions. Figure 1.2 shows the CMS system in the southeast Michigan area.

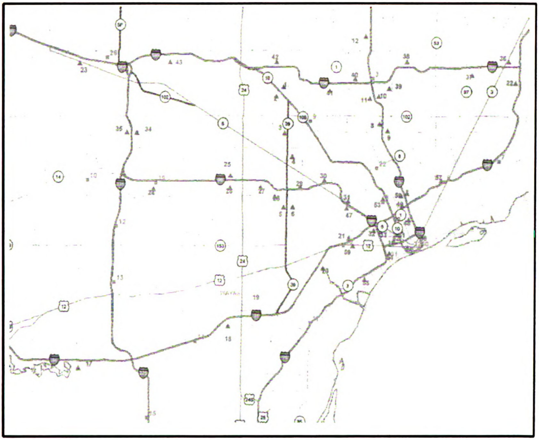


Figure 1. 2 CMS System in Southeast Michigan

1.5 Description of the Problem

Many previous studies have measured the performance of Changeable Message Sign systems through Stated Preference (SP) or Revealed Preference (RP) methods. Very few studies used the field study method. These SP or RP approach methods collect data based on survey questionnaires (field, mail, telephone, etc.), focus group interviews, and on-screen or full-scale driving simulators. However, these methods have a number of key limitations. Firstly, the data is collected under controlled hypothetical scenarios created by the researcher so the results are always under a scaled response. Secondly, the responses directly indicate the whole impact based on a sequence of prior results; therefore, some valuable considerations may not be interpreted correctly. Finally, the most critical shortcoming is that respondents may vary their answers at different times and they often over-state their actual behavior. Therefore, attitudinal surveys or simulations that simply ask people how they will respond in a given situation are not generally viewed as reliable (although participant responses can provide some indication of relative behavior).

Due, at least in part, to these reasons, the reports on the effectiveness of CMS were not consistent across previous studies. Some of the previous research concluded that the CMS system influences drivers' en-route travel choices, diverting them to less-congested routes thereby alleviating downstream congestion and improving a wide level of highway-network performance measures. Conversely, other studies concluded that CMS only minimally influence driver diversion behavior, thus reporting that they do not provide cost-effective benefits to either the transportation system or the drivers (Schiesel and Demetsky, 2000).

1.6 Objective and Scope

The purpose of a CMS system is to reduce congestion, and improve safety and network performance by providing real-time traffic information. However, given the same information, each of the CMS deployment locations are not likely to produce the same level of effectiveness. Under various conditions, based on human, traffic, and geographic characteristics, the CMS likely vary in their effectiveness. No evaluation of CMS system performance using observed field data were found in the literature, and no studies have evaluated their effectiveness under various conditions.

Broadly stated, the objectives of this research are to measure the performance of CMS and to compare their effectiveness as a function of the human, traffic and geographic conditions. The scope of research includes:

1. Identifying Measures of Effectiveness (MOE) to quantify the impact of CMS
2. Measuring the impact of CMS on the selected MOE under various conditions, and
3. Developing recommendations for the future placement of CMS.

1.7 Research Approach

This research is based upon the analysis of empirical field traffic data collected in the metropolitan area of Detroit, Michigan. The traffic data, such as volume, speed, and occupancy, were collected by Inductive Loop Detectors (ILDs) which store minute-by-minute traffic data, 24 hours a day and 365 days a year. The effectiveness of a CMS message is measured by the percent of traffic that diverts to an alternate route during the time the CMS displays a message. The traffic is measured by comparing the downstream traffic volume with the upstream traffic volume when the CMS was displaying a message with similar measurements under normal conditions (Non-message). Therefore, two different conditions (an accident condition with a CMS message and normal conditions without a CMS message) are compared by collecting traffic volume data at different locations (one upstream and the other downstream) of an interchange.

This study developed a method to estimate travel time between the upstream and downstream locations using the discrete ILD traffic data. The sensitivity of the diversion to four different factors; visual literacy, familiarity and time constraints, historical or existing traffic conditions, and geographic location were tested.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Changeable Message Signs (CMS), also known as Variable Message Signs (VMS), or Dynamic Message Signs (DMS), are the most commonly used Advanced Traveler Information System (ATIS) devices in the United States. A CMS provides non-personalized but real-time information on traffic congestion or potential delays to drivers. This information is intended to influence drivers' en-route travel choices, diverting vehicles to less congested routes such as an alternate freeway or arterial surface road. This diversion reduces the duration of the congestion, improves the level of service and network performance, and enhances traffic safety. Different Measures of Effectiveness (MOE) can be used to measure the performance of traffic system control devices, depending on the data collection approaches and research purpose.

A driver's decision to divert from their present route to an alternate route is affected not only by traffic information, but by many other factors. Therefore, an understanding of how these other factors influence a drivers' route diversion behavior is very important in determining where to place CMS to achieve the desired diversion.

This chapter provides a review of previous research related to the objectives of this study. The chapter is broken down into five different sections. Firstly, characteristics of CMS are described; secondly, data approach methods to identify and quantify human behavior are indicated; thirdly, the literature on drivers' driving characteristics is reviewed; and fourthly, factors affecting a drivers' route diversion decision is explored. Finally, prior CMS performance and functional evaluation studies are reviewed.

2.2 Characteristics of Changeable Message Signs

Changeable Message Signs (CMS) are intended to provide en-route real-time information to drivers and alert them to sudden or unexpected changes in traffic conditions. The message displayed may be in the form of either simply an information message, or as an advisory message. In addition to the CMS, drivers may receive information from other sources, such as commercial radio traffic reports. This information is used, along with their own travel experience, to make en-route travel choices, such as diverting to alternate less congested routes.

2.2.1 Brief History of CMS Use

CMS have been used in highway applications in the United States for over 30 years. The first CMS were operated by sliding appropriate messages into a CMS board. Fold-out, blank-out (including neon), rotating drum, and rotating tape (scroll) signs then came into being and provided the capability to display information in "real-time". Even though these signs were innovative at that time, they were only capable of displaying a small number of messages. With computer technology, CMS now have the capacity to display a nearly unlimited number of messages.

In the early 1970s, the bulb matrix became the most popular technology for motorist information systems. However, new technologies such as fiber optics, lightemitting diode (LED) and liquid crystal displays (LCD), which have lower operating costs and improved visibility are used today.

2.2.2 CMS Types

There are two different types of CMS used on the roadways: a portable CMS (PCMS) and a permanent CMS. Typically, permanent CMS are used on high density roadways to advise the driver of both non-recurring congestion and recurring congestion. PCMS are typically used only for non-recurring congestion caused by temporary capacity reductions from construction, maintenance or severe weather conditions.

2.2.3 CMS Message Contents

Message Elements

CMS can be used as any of the three sign categories; advisory signs, guide signs, or regulatory signs. Messages can contain words, numbers or symbols and are used to provide traveler information, to warn of accident or incident conditions, or display speed limits or lane restrictions.

Message Format

A consistent format reduces the time required to understand the meaning of the message. If the information is presented in a non-standard format, it may confuse drivers, and will increase the time required to understand the message. Guidelines on the design of CMS, contained in the Manual on Uniform Traffic Control Devices (MUTCD), suggest the following message elements in the sequence shown:

- What is the problem;
- Where is the problem; and
- What is the effect (or suggested action)

The recommended configuration of a CMS boards is shown in Figure 2.1.

Figure 2. 1 CMS Configuration

2.3 Data Approach Method

Three different approaches or methods have been used to identify and quantify human behavior; Stated Preference (SP), Survey based Revealed Preference (RP) and field studies.

2.3.1 Stated Preference (SP) Approach

The Stated Preference (SP) approach relies on respondents making their choices when presented with hypothetical scenarios. The respondents are asked to indicate their preferences among a set of hypothetical alternative choices such as "*If, under certain specified conditions, you were presented with each of these different alternatives, which one would you most prefer? Which is next?*" Respondents rank, rate or choose the alternative from among the set of hypothetical scenarios, which are described by a set of attributes generated from an experimental design. The highest ranked attributes (from those included in the questionnaire) are assumed to represent the respondent's behavior, and are then used to estimate that driver's behavior when presented with real choices. This is a useful approach when attempting to extend our understanding into areas that cannot be tested under real conditions due to cost or safety considerations. Two techniques used to extract data are surveys and simulators.

2.3.2 Revealed Preference (RP) Approach

The Revealed Preference (RP) approach is attributed to Samuelson (Economist, 1938). He hypothesized that individual behavior could be described as a series of choices, so respondents' actual choices reveal the individuals' behavior when presented with available alternatives. Revealed preference data is gathered based on surveys asking about previous actions, or direct observations in real-life situations (field study approach). The advantage of the RP Approach is the reliance on actual choices, avoiding the potential problems associated with hypothetical responses such as strategic responses or a failure to properly consider behavioral constraints.

However, there are several limitations to the use of the RP approach. First, it is very difficult to observe the effect of large variations in the variables. Second, there are often strong correlations between the variables in revealed preference data (e.g., travel time and travel cost) so it is often difficult to separate the effect of different variables. Third, it is difficult to estimate utility levels attributed to secondary variables, as opposed to primary variables. Therefore, the utility weight assigned to secondary variables is usually low. Finally, RP data is based on choices from actual alternatives, and it is difficult to forecast the responses to new alternatives. Table 2.1 shows the different characteristics of the SP and the RP methods.

Table 2. 1 Characteristics of Stated and Revealed Preference Data Approaches

Stated Preference (SP)	Revealed Preference (RP)
Based on hypothetical scenarios	Based on actual behavior
Attribute framing errors	Attribute measurement errors
Extended attribute range	Limited attribute range
Attributes uncorrelated by design	Attributes correlated
Intangibles can be incorporated	Hard to measure intangibles
Can elicit preferences for new alternatives	Cannot directly predict response to new alternatives
Preference indicators can be rank, rating, or choice	Preference indicator is choice
May be cognitively non-congruent	Cognitively congruent with choice behavior

2.3.3 Field Study Approach

The field study approach analyzes human behavior or attitude through real-time field data observation. The actual behavior in response to stimuli is measured by observation. The field study approach has all of the limitations of the Revealed Preference (RP) approach, and in fact is a subset of this more general approach.

2.4 Drivers' Driving Characteristics

2.4.1 Route Choice Behavior

Several previous research studies investigated drivers' route choice behavior. Huchingson, McNees, and Dudek (1977) studied commuter route choice behavior using interviews and mail-in surveys in Dallas and Houston, Texas. This study collected survey data at two different locations: one in the Central Business District (CBD) of Dallas and the other at a rest stop along an Interstate highway leading into Houston. Drivers were asked to describe the routes they regularly took to work and home, and the reasons why they had chosen the present route. The most frequent reasons for taking the priority route were that it was more convenient, direct or faster, and the alternate routes took longer and were less direct. The survey results at the two different locations are given on Table 2.2. There is clearly a different sequence of priorities that commuters and intercity drivers used to select their priority route. A faster and shorter route had a higher priority for commuters while convenience and accessibility were more important to intercity drivers.

Table 2. 2 Reasons for Taking Primary Routes (Huchingson et al. 1977)

Reason	Percentage of Drivers		
	Commuters		Intercity Drivers
	Home-to-Work	Work-to-Home	
Fastest route	23	24	20
Fewest stops	14	8	3
Convenience and accessibility	12	6	46
Shortest, most direct	22	14	20
Less traffic	8	19	5
Good traffic flow	5	10	0
Other	16	19	7

Depending on when drivers choose their driving route, two different route choice behaviors have been described: one is pre-route choice (deciding the route before departure) and the other is en-route choice (deciding on a route while driving on the road). Research conducted in Chicago, Illinois by Deniels, Levin and McDermott (1976) indicated that 69 percent of home-to-work and 64 percent of work-to-home drivers always choose their route before departure and only 7 and 11 percent of home-to-work and work-to-home drivers modify their route while on the road.

Khattak, Schofer and Koppelman (1991), also in Chicago, Illinois found similar results. Seventy-four percent of the drivers in that survey answered they choose the route before getting in the car for the home-to-work trip. When questioned about how often respondents modified their route, slightly more than 80 percent of the respondents stated they had used the same route for more than 1 year, although they had made minor diversions occasionally.

Polydoropoulou, Ben-Akiva, and Kaysi (1994) attempted to define the preference factors in route choice using a Likert-style survey. The Likert-style survey uses questionnaires based on a rating scale (generally five point scales such as strongly disagree to strongly agree) to determine respondents feelings or attitude. The respondents indicate their feelings based on various statements providing a series of reliability statements for each person's attitude. The data were obtained from Massachusetts Institute of Technology (MIT) commuters. Table 2.3 shows the results from this study. Category 1 corresponds to the response "Not important at all", whereas category 5 corresponds to "Very important". Time of day (61.2 percent), commute time (76.1 percent), and time spent stopped in traffic (79.1 percent) were reported to be very important factors to the drivers when they choose their route. Traffic reports (18.5) and weather (38.0 percent) were relatively less important to the drivers in this survey. It is interesting to note that habit is rated "very important" nearly four times as often as traffic reports. Traffic reports have the highest frequency of "not important" responses.

Table 2. 3 Importance of Factors Affecting Route Choice Behavior (Polydoropoulou et al, 1994)

Number	Attribute	Not Important				Very Important
		1 (%)	2 (%)	3 (%)	4 (%)	5 (%)
1	Time of day	15.7	7.1	11.1	16.3	44.9
2	Commute time	9.2	4.6	10.0	20.6	55.5
3	Habit	12.3	8.6	29.8	26.1	23.3
4	Time spent stopped in traffic	5.3	5.3	10.3	29.0	50.1
5	Number of traffic lights	10.9	11.5	24.2	25.4	27.9
6	Traffic reports	30.7	22.7	28.1	12.4	6.1
7	Risk of delay	8.6	8.5	26.1	30.6	26.2
8	Weather	25.9	16.7	19.3	15.9	22.1

Wenger, Spyridakis, Haselkorn, Barfield, and Conquest (1990) studied the motorist behavior and decision making using personal interviews in Seattle, Washington. Seventy-three percent of Seattle commuters reported that they received some traffic information before their departure to work and half of them received traffic information pertaining to their regular route almost immediately after awakening. However, the majority of commuters answered that they rarely decide to use an alternate route (65.7

percent), rarely decide to use an alternate mode (90.0 percent), and rarely decide to change their departure time (64.3 percent) on the basis of traffic information received before departure. Therefore, this study indicated that while commuters may receive pre-departure traffic information, only about a third of the drivers stated that they use this information in their route choice.

2.4.2 Knowledge of Alternate Routes

Shirazi, Anderson, and Stesney (1988) conducted a telephone survey concerning commuter attitude and characteristics in Los Angeles, California. More than 70 percent of commute drivers reported they have knowledge of alternate routes while 27 percent stated they do not. This study categorized the respondents who know of an alternate route by age, gender, travel time and delay. No significant relationship was found between knowledge of alternate routes and age, gender, and delay. However, a significant relationship was found between knowledge of an alternate route and travel time. The drivers who commute for less than 45 minutes are more likely to know of an alternate route than those with a travel time greater than 45 minutes.

A study from Wenger, Spyridakis, Haselkorn, Barfield, and Conquest (1990) measured the knowledge of a drivers' primary route and alternate routes based on how well they could name landmarks and street names on each route. Table 2.4 shows the means and standard deviations for the number of street names and landmarks named on each route. The drivers were much more familiar with the street names and landmarks on the primary route than on the alternate routes. The drivers reported their decision to use an alternate route was based first on en-route traffic information and secondly on observed traffic condition. When drivers did use an alternate route for any reason, 77.8 percent of commuters answered that they had experienced an increased stress level on the trip.

Table 2. 4 Number of Names and Landmarks in Route Descriptions (Wenger et al, 1990)

		Primary Route	Alternate Route 1	Alternate Route 2
Street Names	Mean	8.45	5.02	4.26
	SD	6.23	3.70	4.01
Landmarks	Mean	1.67	1.03	0.79
	SD	1.89	1.48	0.90

SD: Standard Deviation

2.4.3 Route Switching Behavior

Research conducted by Shirazi, Anderson, and Stesney (1988) investigated the route changing or switching behavior for home-to-work commuters in Los Angeles, California. Forty percent of respondents indicated they had changed their route during the home-to-work trip at least once, while thirty-one percent never did and twenty-nine percent gave an invalid response. Only fourteen percent of the respondents who had changed their route reported that they change their route "*very often or often*" and approximately twenty-five percent of the respondents answered "*rarely or sometimes*". The majority of route changes occurred when drivers observed traffic congestion. Similar results were reported by Polydoropoulou, Ben-Akiva, and Kaysi (1994) who found 62 percent of the drivers who switched routes changed their route based on their own observation, 12 percent diverted based on radio information and 26 percent for other reasons.

Mahamassani, Caplice, and Walton (1990) conducted a study focused on time- and route-switching behavior of commuters in Austin, Texas. Nearly 3000 randomly selected households in a mostly suburban area of northwest Austin close to a major technology-based manufacturing and research area were interviewed. Thus, the sample data was not exclusively CBD oriented commuters, but included a large proportion of suburban workers. Figure 2.2 shows the results of route switching behavior based on two different trip purposes. The results indicated that a higher proportion of commuters adjust their departure time for the home-to-work trip than for the return trip. A slightly larger proportion of home-to-work commuters adjust their departure time than switch routes. On the work-to-home commute, a larger proportion of drivers adjusted their routes compared with the home-to-work commute. Also, a significantly larger proportion of commuters responded that they were more likely to adjust their travel route than departure time for the work-to-home trip. These results indicate the switching behavior may be based on different considerations between the home-to-work and work-to-home commute.

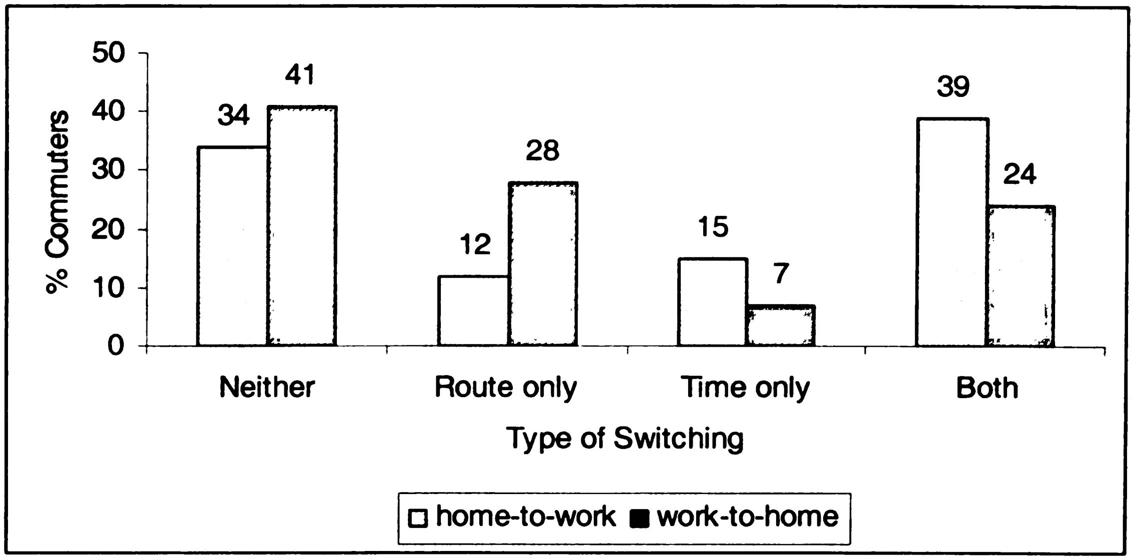


Figure 2. 2 Route and Time Switching for Home-to-work and Work-to-home Trips (Mahamassani, Caplice, and Walton 1990)

2.5 Factors Affecting a Drivers' Route Diversion Decision

2.5.1 Factors Related to Human and Socioeconomic Characteristics

Khattak, Schofer and Koppelman (1991) investigated factors influencing en-route diversion behavior through a survey in Chicago, Illinois. The results of this research indicated that some human characteristics, such as gender and self-assessment statements about risk behavior, significantly affect the diversion behavior. For example, among the people who have knowledge of alternate routes, men (62 percent) were more likely to change travel routes than woman (38 percent) and a person who states they are more willing to take risks and have an interest in discovery and exploration, has a more aggressive diversion behavior. However, Mahmassani, Caplice, and Walton (1990) found different results in their research in Austin, Texas. In particular, their research indicated that gender, as well as age or work place rules do not significantly effect drivers' route diversion. This study concluded that the home-to-work route diversion is primarily motivated by geographic considerations and network considerations rather than by socio-demographic characteristics. However, departure time switching for this trip was clearly influenced by lateness tolerance, job position, and other individual characteristics.

Polydoropoulou, Ben-Akiva, and Kaysi (1994) developed a route diversion model based on revealed preference data. From their analysis, when drivers are under time pressure, and drivers who often change their regular routes while driving, have the highest probability of route diversion.

Ratim Pal (1998) attempted to identify drivers' diversion decisions using an integrated framework which involved observable socioeconomic and situational factors, and unobservable latent factors (such as risk acceptance, trust in traffic information systems, and the expected level and quantity of the information). From their observation, commuters who have a high-risk-taking tendency and have more trust in the traffic information system were more likely to divert compared with commuters who were looking for more detailed information (a low-risk-taking tendency).

2.5.2 Factors Related to Traffic Conditions

Several previous studies investigated the relationship between route diversion and traffic congestion. Heathington, Worrall, and Hoff (1971) used revealed preference (RP) to evaluate driver behavior toward route diversion to avoid unexpected delay in Chicago, Illinois. The results of this research indicated that most drivers are more willing to divert when they encounter non-recurring congestion than when they encounter recurring congestion. Also, typically, home-to-work trip drivers are more willing to divert than work-to-home trip drivers. From the diversion percentage results based on the highway functional classification, expressway drivers were slightly more willing to divert than the non-expressway drivers when they were faced with the same amount of delay. However, this difference was not statistically significant.

Huchingson and Dudek (1979) conducted a study to find freeway motorists' preference and behavior with an imaginary field test. The test was conducted with various groups from different locations in the United States. The first test measured the percentage of drivers who stated they would divert for various levels of delay time from incident conditions. Fifty percent of drivers stated they would divert for a delay exceeding 15 to 20 minutes. Longer delays naturally induced more drivers to state that they were willing to divert. However, in severe weather conditions such as rain or ice, the stated willingness to divert was low for up to an hours' delay. More drivers indicated they were willing to divert when the displayed information contained the duration of delay than when only the type of incident or level of congestion was displayed. There was no significant difference in the response to the delay from different types of incidents such as roadwork, an accident, a truck over-turned, or weather conditions such as snow, ice, and rain. The overall conclusions from this study indicated that as delay increased on the regular or preferred route, an increasing number of drivers state that they would divert to an alternate route, and the relationship between length of delay and percentage of diversion resembles an *S-shaped* curve. Figure 2.3 shows the shape of the effect of delay on the percentage of driver diversion.

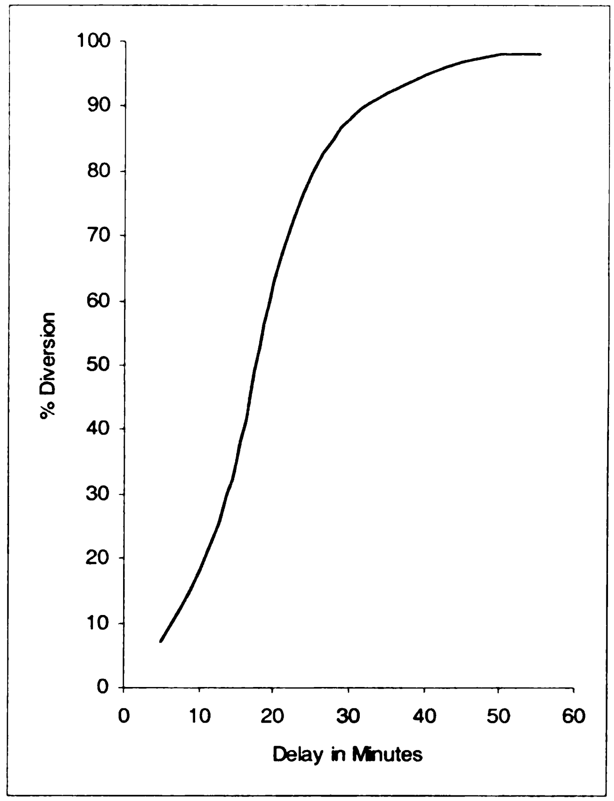


Figure 2. 3 Effect of Delay on Drivers Diversion (Huchingson et al. 1979)

This study also investigated the motorist perception of the delay duration when the adjectives "MAJOR" and "MINOR" are used to modify the word "ACCIDENT". The median value of the expected delay for *"Minor Accident"* meant *"a delay of 12 minutes or less"*, where as *"Major Accident"* meant *"a delay of 22 minutes or more"*. A similar study was conducted by Huchingson, Whaley, and Huddleston (1984). The results supported Huchingson and Dudek's (1979) finding that major accident means *"a delay of 22.7 minutes or more"* and a minor accident as *"a delay of 7.9 minutes or less"*.

Khattak, Schofer and Koppelman (1991) investigated the influence on commuters' route diversion in response to delay with a stated preference (SP) survey in

Chicago, Illinois. About sixty-two percent of the surveyed drivers had experienced en-route delay during the past 6 months and 84.6 percent of drivers expected 10 – 30 minutes of delay from recurring congestion on their work trips. Thirty nine percent of drivers stated that they would divert to an alternate route in response to an expected 10 – 20 minutes of additional delay. As expected, more drivers (49 percent) stated they would divert in response to an estimated increase in delay of 21 – 30 minutes. However, the percent of drivers who would divert for an expected extra delay of more than 30 minutes did not increase, and the percentage actually decreased when more than 40 minutes of extra delay was expected.

These results were based on a small sample, and this may have contributed to the counter-intuitive results. When asked about their past experience with diverting to an alternate route, more than seventy percent of respondents who diverted believed that they saved travel time, and over fifty percent of respondents who did not divert believe that they would have saved time by taking their best alternate route.

2.5.3 Factors Related to Traffic Information

Daniels, Levin and McDermott (1976) conducted a home-interview survey in Chicago to investigate diversion based on radio traffic reports. The survey responses were divided into two groups of drivers, expressway and non-expressway. Over 70 percent of both expressway and non-expressway drivers listen to radio traffic reports on the way to work. Among them, one out of three expressway drivers and one out of four non-expressway drivers reported they would divert their route on the way to work based on radio information. Reported accidents induced a higher proportion of diversion than simple congestion information among both the expressway and non-expressway drivers.

Huchingson, McNees, and Dudek (1977) also conducted a study to measure the reaction from radio advisory incident information. Two different destination groups (within city and beyond city) were surveyed. Seventy seven percent of respondents with a destination in the city and 65 percent of respondents with a destination beyond the city answered that they would divert their route based on traffic information. The major reason for not diverting was unfamiliarity (66 percent) of the area, and the main reasons for diverting were to avoid congestion (48 percent), save time (27 percent), and avoid delay (20 percent).

These results illustrate the problem with using Stated Preference (SP) techniques to study traffic diversion. The Revealed Preference (RP) studies all found diversion rates of approximately thirty percent, while in this study between 65 and 77 percent said they would divert.

2.6 Prior CMS System Evaluation Studies

There are several previous research studies that evaluated the performance of CMS, and the impact of different CMS displays and designs.

2.6.1 CMS Performance Evaluation

Dudek, Weaver, Hatcher and Richards (1978) measured the impact of real-time special events; the annual Fourth of July fire works, the annual football game between the University of Texas and University of Oklahoma, opening day of the annual Texas State

Fair, and the Cotton Bowl football game, by field observation in Dallas, Texas. This study evaluated 14 real-time messages displayed on matrix signs located on the freeway. The diversion of freeway traffic to an arterial alternate route was used to measure the driver response. From the analysis results, around 40% of drivers diverted to the alternate route based on the CMS message. However, when a single sign displaying a credible message was installed at the proper location, the diversion was the same as when several advance signs were used. Therefore, this study concluded that repetition of messages is not necessary if the messages are credible and located properly. Also, drivers are more affected by messages which describe traffic conditions than with best-route messages.

Turner, Dudek, and Carvell (1978) conducted a study to measure the influence of CMS during maintenance operations in Dallas, Texas. The traffic flow rates on freeway exit ramps during incident conditions with and without messages displayed on a CMS were analyzed on a case study basis. From the analysis results of this study, it was concluded that more diversion was generated when a message is displayed than under normal conditions (natural diversion). Table 2.5 shows the case study results in this study.

Table 2. 5 Case Study Results (Turner, Dudek and Carvell, 1978)

Case	Change of 5-minute Flow Rates for Exiting Traffic (%)		
	No Message	Information Sign	Diversionary Sign
1	+19.0	+324.7	+343.8
2	-	-	-
3	+152.6	+176.3	+227.3
4	+96.2	+125.9	+147.3

The results are the 5-minute flow rates for exiting traffic. The exit traffic flow increased significantly when a CMS message was provided compared with no messages. Moreover, exit volumes increased more when the signs displayed messages recommending diversion when compared to traffic information only messages. Therefore, this would indicate that drivers prefer diversionary information to only incident information.

Dudek, Stockton, and Hatcher (1982) evaluated the impact of CMS messages in San Antonio, Texas. This study assessed the effectiveness of CMS in diverting traffic to an alternate freeway route during incident conditions. The traffic volume on the freeway and off-ramps were collected from field traffic data counters. Three different conditions; (a) during normal conditions, (b) during an incident without the CMS messages, and (c) during an incident with the CMS messages were compared using seven different incident cases. Combining the results for all seven incident cases, the diversion volume during an incident but with no CMS message was significantly higher ($p<.05$) than normal conditions and the diversion volume during an incident with a CMS message was also significantly higher ($p<.05$) than normal condition. However, there was no statistical difference in the diversion volume during the incident conditions between with and without CMS message cases.

The data were analyzed to determine whether diversion rates were affected by the time of day when the incident occurred. During the peak-hours, the diversion rates both with and without a CMS message, were significantly higher than normal condition. However, there was no statistical difference in the diversion rate during the off-peak period. According to the results from this study, the use of a CMS message during incident conditions did not have a significant effect on drivers route diversion when compared to natural diversion (without a CMS message). This study concluded that drivers, generally, select their travel route based on the time of day, location of the incident, and severity of congestion, and the rate is not affected much by the CMS information.

Yim and Ygnace (1996) investigated the effectiveness of the Systemed' Information Routiere Intelligible aux Usagers System (SIRIUS). SIRIUS is the large urban field traveler information and automated traffic management system in Paris, France. It provides real-time traffic information via remotely controlled CMS operated from regional Traffic Management Centers. Yim and Ygnace assessed the performance of SIRIUS with a link flow evaluation using loop detector data. This study evaluated one link which is an access ramp connection between an arterial route (D45) and a freeway route (A86). Freeway route A86 is the ring road that wraps around the suburbs of Paris, and arterial route D45 is the frontage road serving the residential and industrial districts along the freeway. Therefore, drivers can make a choice to either stay on the arterial route or take the freeway route to avoid congestion based on the CMS message.

The traffic data such as volume, speed, and density at the access ramp connecting D45 to A86 were collected using three loop detectors. A CMS was placed 300 m upstream from the diversion point and displayed the length of queue on A86 at all times, including free-flow conditions. Two different conditions were analyzed. The short-term condition measured the traffic volumes during the 5 minute period before and after the message changed. The long-term condition measured the traffic volumes during the 10 minute period following the 5 minute period after the message changed.

When the message changes to indicate increased traffic congestion on A86, the mean flow rate on the ramp to access A86 during the 5 minute period after the message changed decreased by 3.68 percent. When the message changed to indicate a decreased level of congestion on A86, no significant difference in the mean flow rate was observed. Also, the data showed that the queue distance and diversion rate were positively related. When the CMS displayed a queue length of 1-km, 2-km, 3-km and 4-km, the traffic flow on the access ramp reduced by 7, 10, 15 and 30 percent respectively. This reduction was greater during the AM-peak hours than the PM-peak hours. This study indicated that the CMS significantly impacts vehicle diversion and has the greatest effect when the information is disseminated during periods of increasing congestion.

Krraan, Zijpp, Tutert, Vonk and Megen (1998) evaluated the performance of a dynamic CMS system in Amsterdam, Netherlands. This study compared aggregate performance measures such as severity of congestion, traffic performance, instantaneous travel time delay and average travel speed before and after the CMS installation. The measurements were conducted at seven CMS locations and only the queue length information in each travel route was provided by the system. Congestion was measured by the length and duration of queues. The Motorway Control and Signaling System (MCSS) provided time and link based binary congestion information such as "1" if congestion occurs and "0" otherwise.

The traffic performance was measured by vehicle-miles-traveled (VMT) which was calculated based on traffic volume and the length of the links during each time period. The instantaneous travel delay was measured by the difference between free flow travel time and realized travel time, which was weighted by traffic volumes. In addition, the standard deviation of speed over the entire network was measured to analyze the performance of the CMS system. This study assumed that improved network performance leads to a decrease in the variation of travel speed and is an indicator of more reliable travel times. From the analysis results, the severity congestion over the entire network was slightly decreased and traffic performance improved after applying the CMS systems. Even though the average speed over all the links did not increase, the delay time decreased in both the morning and evening peak hours. Overall, the authors concluded that the CMS system had a positive impact on network performance on the Amsterdam freeway system.

Peeta and Gedela (2001) evaluated the performance of a proposed CMS system with simulation experiments using DYNASMART, a mesoscopic traffic simulator. The experiments used the Borman Expressway corridor network, which consists of 197 nodes and 458 links and drivers' CMS response attitudes collected by a stated preference (SP) survey. The experimental simulation compared the network performance with and without CMS information under different scenarios with variation in the number of incidents, incident duration and congestion level. The simulation results showed that CMS information improved System Optimal (SO) solutions ranging from 13 to 25 percent compared with the no-information case.

The second simulation varied incident duration (5min, 10min and 20min). The network performance gradually increased as incident duration increased. Therefore, it could be interpreted that a CMS will be more effective with more severe incidents. The last experiment compared the performance of CMS under different congestion levels.

With medium congestion, CMS provides the greatest improvement in the system performance compared with the low and high congestion levels. At the extremes, the opportunities to divert to better paths through CMS messages are reduced because of low and high network congestion. Overall, this study indicated CMS control would provide positive performance results in the real world.

2.6.2 User Impacts Based on Different Designs and Features of CMS

Many state Departments of Transportation (DOT) are currently operating two different types of dynamic CMS messages, a static message and a flashing message for attracting attention and emphasizing the importance of the message to drivers. Dudek (2004) conducted a study comparing the effectiveness of using three different features of the dynamic CMS messages; 1) Effect of flashing an entire one-phase message 2) Effect of flashing one line of a one-phase message 3) Effect of alternating text on one line of a three-line CMS while keeping the other two lines of text the same.

The results of flashing an entire one-phase message had no significant effect upon driver comprehension compared with the static message. However, the flashing feature required 1.5 seconds longer reading time to comprehend the message than the static sign. Flashing one line of a message reduced the ability of drivers to remember parts of the message when compared with the static message. The average reading time of the message increased 1.8 seconds compared with a line that was not flashed. The last feature, which has three lines including redundant information by repeating the top two lines on both phases of a two-phase message while changing the bottom line, was not significantly different than with a message without redundancy. The average reading time of the message that had redundant information was 2.8 seconds longer than the message which did not include redundant information. From the test results, the flashing messages requires a longer reading time, but only provides the same efficacy as the static message.

Hustad and Dudek (1999) conducted a study to evaluate and develop abbreviations on Changeable Message Signs (CMS) using a human factors laboratory in New Jersey. This study indicated that there were regional differences with respect to driver understanding of some of the abbreviations. For example, Eighty-eight percent and 85 percent of the drivers tested in northern New Jersey understood the abbreviations EXP CLSD and LOC LNS for "Express Closed" and "Local Lanes", whereas less than 70 percent of the drivers studied in southern New Jersey understood these abbreviations. Also, the abbreviations for some of the facilities/structures were generally understood by a very high percentage of drivers who live near the facility/structure. For example, the abbreviations studied for "Mount Tabor" and "Sandy Hook National Park" which are located in north New Jersey were understood by 88 percent of the drivers tested in that part of the state. In contrast, only 58 and 65 percent of the drivers tested in south New Jersey understood the abbreviations.

Brian G. Benson (1996) studied motorist attitudes toward the message content of CMS, using as a case study the CMS system of Northern Virginia. The case study was carried out using seven focus groups and an opinion survey. This study indicated that a distinct negative correlation (-0.25) was found between motorists who had experienced inaccuracies on CMS and those who are likely to use alternate routes recommended on a CMS. It is twice as great as that between motorists who had experienced CMS inaccuracies and those who are often influenced by CMS (- 0.12). This result reflects that those who use a recommended route based on CMS will be more negatively affected by having experienced CMS inaccuracies. From the survey responses to questions about posting delays in travel time from heavy congestion, respondents were evenly divided between two groups: one prefers information to be quantitative and the other prefers information to be descriptive. Among the respondents who prefer quantitative information, half want a range estimate (e.g., 10 – 20 minute delay) and the remaining half want a point estimate (e.g., 15 minute delay).

2.7 Summary

From the literature, there is evidence that most drivers decide their driving route before departure (pre-route choice) and have one regular route, especially for their commute trips. The factors used to select a regular route are different based on the characteristics of the trip. Generally, commuters place a higher priority on a faster and shorter route while the non-commuter trips place priorities on convenience and accessibility. The literature leads to the conclusion that the preference in route choice or diversion is not only affected by the drivers' characteristics, but also by factors such as the trip purpose, geographic and network location, traffic conditions (risk of delay), visual confirmation of traffic congestion and severe weather conditions.

The results concerning the effectiveness of CMS on the drivers' route diversion behavior are not consistent. Some of the research concluded that the CMS do not have a significant affect on the drivers' route diversion behavior, while other research indicated that the CMS have a significant affect on route diversion behavior, especially during an incident condition.

There are several possible explanations for these inconsistent results in the previous research. First is the study technique. Some of the previous research evaluated the effectiveness of CMS with Stated or Revealed Preference approaches conducted by survey or simulators. These methods analyzed the respondent's behavior based on the participant response, and then assume the responses are the same as the actual choices drivers would make under real conditions. However, respondents may vary their answers at different times or locations and they often over-state their actual behavior. Therefore, results based on survey data in a given situation may not be reliable.

Second, questionnaires are created under hypothetical scenarios constructed by the researchers, and they may not include all valuable considerations. Therefore, the results are always measured under the factors included by the researchers.

Third, the literature which analyzed the effectiveness of the CMS by observing traffic diversion in the field, did not consider all the factors which potentially affect drivers' route diversion; Drivers' route diversion attitudes are not consistent at all times of day; drivers' route diversion behavior is different for different trip purposes; and drivers route diversion varies with familiarity with the location. The effect of a CMS may also differ based on geographic locations. That is, a location with a freeway alternate route and a location without a freeway alternate route may evoke different diversion reactions from the same CMS information.

The literature indicated that drivers are very sensitive to anticipated versus observed congestion. Therefore, an accident condition where drivers can observe the congested queue and where they cannot observe the congestion queue might have a different effect. However, this factor was not reported (or presumably considered) in most of the study results.

Finally, the literature does not consider the effectiveness of CMS under expected traffic conditions. When the demand exceeds the system capacity during the peak period, congestion (called recurring congestion) is created. If drivers expect that recurring congestion is likely to be present, based on their experience, they may react differently.

In this study, the effectiveness of CMS will be analyzed with field traffic data to provide more reliable results and will consider those factors that potentially effect a drivers' route diversion behavior, but were not considered in the previous research.

CHAPTER 3

DATA COLLECTION

3.1 Introduction

For this research, the Michigan Intelligent Transportation System Center (MITSC) in Detroit provided traffic data from Inductive Loop Detectors (ILD) and the CMS message log from May - December 2001 and February - December 2002. This research utilized the data to analyze the effectiveness of the CMS.

3.2 Description of Inductive Loop Detector Data

The ILD traffic data consists of volume, speed and occupancy and is summarized and reported in one minute increments by lane 24-hours a day and 365 days a year. Each report consists of five different fields, loop-ID, volume, occupancy, average speed, and date/time. Each loop-ID consists of one or more lanes and each lane has an individual detector to measure traffic. Information about each of the study sites, including the number of lanes, type of loop, site name and corridor information was developed for each loop-ID. The aggregation of the individual loop-IDs at each site, called the Rep_ID, contains data on all lanes passing the location. The Rep_ID was depicted on the files provided by MITSC. Table 3.1 shows the format of the ILD traffic database.

Table 3. 1 Format of Inductive Loop Detector Data

Field	Contents
Field 1	Loop-ID associated with Rep_ID (site-ID). - Typical ID is a 6 or 7-digit integer.
Field 2	Volume - An integer count of vehicles during the past minute - Typical values are 0 to 70 - A blank means that no data was received from the Inductive Loop
Field 3	Occupancy - Percent of time the loop was occupied by a vehicle during the past minute - Typical values are integer 0 to 100 - A blank means that no data was received from the Inductive Loop
Field 4	Speed - The average vehicle speed in miles per hour - Typical values are integer 0 to 100 - A blank means that no data was received from the Inductive Loop
Field 5	Date/Time stamp YYYY-MM-DD hh:mm:ss denoting the end of the minute

3.3 Description of CMS Message Log Data

The CMS message log database consists of date and time of operation, operator name, sign hardware, sign number, activity type, and message information. The message to be displayed when accidents or other events occur are selected by the MITSC traffic engineer/operator based on information received from a responsible authority. Depending on the direction, location, and nature of the incident, the message is selected from a message library developed by MDOT, or message guideline, or it can be composed by the operator. To avoid diminution of system credibility, overly precise descriptions were not provided by the system. Depending on the impact of an incident or other events, messages can be displayed at more than one CMS upstream location. The messages included accidents, disabled vehicles, construction, maintenance activities (road work, lane closure, debris pickup), severe weather (heavy rain, heavy snow, fog, thunderstorm), amber alter, ozone-action days, and holiday traffic information. The displayed message was discontinued when traffic conditions returned to normal. Table 3.2 shows the database format of the CMS log message information.

Table 3. 2 Format of CMS Message Log Database

Field	Contents
Field 1	Recording Date and Time
Field 2	User/Operator Name
Field 3	Sign Hardware Number
Field 4	CMS Number
Field 5	Abbreviation of Message
Field 6	Activity Types
Field 7	Detail Activity Information
Field 8	Line 1 Text (What)
Field 9	Line 2 Text (Where)
Field 10	Line 3 Text (Effect)
Field 11	Message ID
Field 12	Message Starting Date and Time
Field 13	Message Ending Date and Time

3.4 Study Site Selection

There are 59 CMS locations in the study area. From these 59 CMS locations, this study selected five locations which were expected to incorporate the variables determined to effect diversion in the literature review. The most important geographic feature was the existence of an alternate freeway route. An alternate route was defined as *"the same level of state- or interstate-highway as the original route"*. Traffic conditions were classified as *"existing and non-existing recurring congestion"*. Recurring congestion was defined as congestion which occurs at a specific location and a specific time period causing the average speed to fall below 35 mph (CALTRANS methodology) for at least 15-minutes. Figure 3.1 shows the five different sites selected based on these criteria. Also, Table 3.3 contains brief information about each study site.

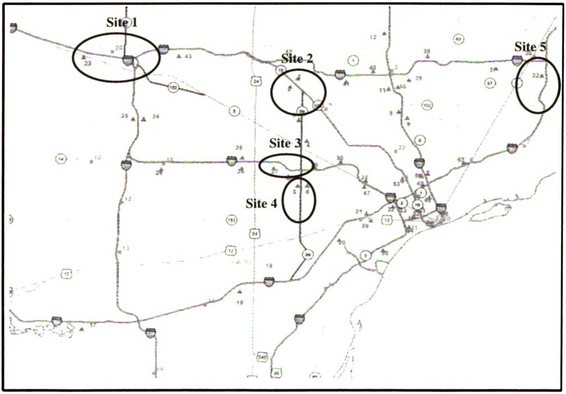


Figure 3. 1 Selected Study Sites

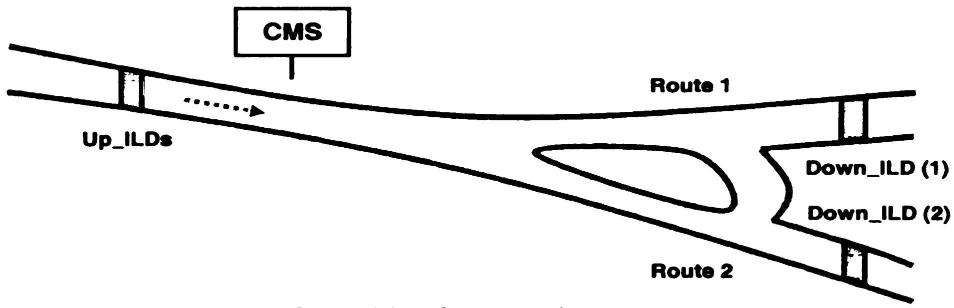
Table 3.3 Selected Study Site Information

Site	CMS ID	Alternate Freeway Route	Upstream			Downstream Alternatives					
			Route	ILD Data	Recurring Congestion	Route 1	ILD Data	Recurring Congestion	Route 2	ILD Data	Recurring Congestion
Site 1	CMS 23	Yes	I-96	Yes	No	I-696	Yes	Yes	I-275	Yes	No
Site 2	CMS 2	Yes	M-10	Yes	No	M-10	N/A	-	M-39	Yes	Yes
Site 3	CMS 28	Yes	I-96	Yes	No	I-96 (Express)	Yes	No	I-96 (Local)	Yes	Yes
Site 4	CMS 5	No	M-39	Yes	Yes	M-39	Yes	No	-	-	-
Site 5	CMS 22	No	I-94	Yes	No	I-94	Yes	No	-	-	-

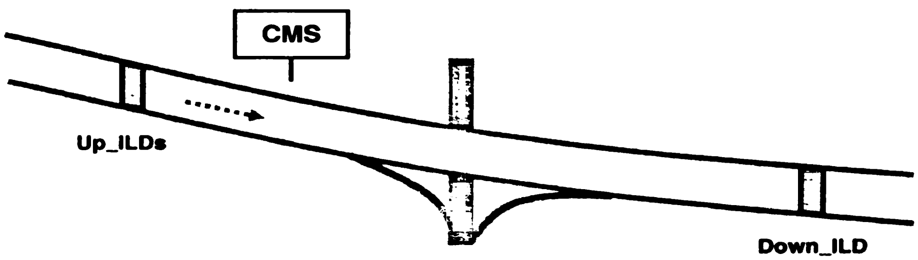
3.5 Data Collection Method

3.5.1 ILD Traffic Data Collection

To measure the diversion, traffic data were collected at two or more different ILD locations at each selected site: one upstream and the others downstream. ILDs which are located slightly before or after the CMS message board were selected for the upstream data collection. Depending on whether the site has an alternate route or no alternate route, one or two downstream locations were selected. Figure 3.2 shows the downstream ILD locations based on these two conditions. In case (a) of Figure 3.2, route 1 and route 2 are alternate routes. Therefore, the diversion rate will be different based on where the accident occurred. In case (b) in Figure 3.2 no alternate freeway route exists but entrance and exit ramps exist between the upstream ILD and downstream ILD.



(a) A Site with a freeway alternate route



(b) A Site without a freeway alternate route

Figure 3. 2 ILD Data Collect Locations

3.5.2 ILD Traffic Data Conversion

The Inductive Loop Detector (ILD) counted and stored traffic volume, speed, and percent occupancy at each lane during each one-minute time period. This ILD traffic data from each lane was aggregated into spot traffic data as follows.

Volume

Minute based lane volume was converted to a spot total lane volume by the following arithmetic equation:

$$Q(t) = \sum_{i=1}^{n} q_i(t)$$

where,

t = *time (minutes)*

i = i^{th} *lane*

n = *number of lanes*

$q_i(t)$ = i^{th} *lane volume at time t*

$Q(t)$ = *total volume at time t*

Speed

In a moving traffic stream, each vehicle travels at a different speed. Thus, the traffic stream does not have a single characteristic speed so the mean speed is used to characterize the traffic stream as a whole. There are two types of mean speeds: time mean speed and space mean speed. Time mean speed is defined as the arithmetic mean of individual spot speeds that are recorded for vehicles passing an observation point over a selected time period. Space mean speed is defined as the harmonic mean of individual speeds which are recorded for vehicles passing an observation point over a selected time period. The harmonic mean is calculated by converting the individual spot speeds to an individual travel time, then calculating the average travel time, and finally inverting the average travel time rate to obtain an average speed. To measure the harmonic average spot mean speed from the lane mean speed, this study used the following equation:

$$\overline{\mu}_{SMS}(t) = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{\overline{v}_i(t)}}$$

where,

t = *time(minutes)*

i = i^{th} *lane*

n = *number of lanes*

$\overline{v}_i(t)$ = i^{th} *lane speed at time t (mph)*

$\overline{\mu}_{SMS}(t)$ = *space mean speed at time t (mph)*

Occupancy

Percent occupancy is defined as the percent of time a point or short section of roadway is occupied. Occupancy can vary from 0 percent (the absence of vehicles passing) to 100 percent (a vehicle completely stopped over a point). Each lane provided the minute based percent occupancy. Lane density was estimated from the lane by lane percent occupancy by the following equation:

$$K(t) = \frac{\sum_{i=1}^{n} \frac{52.8}{\overline{L_V} + L_D} \times \%Occ_i(t)}{n}$$

where,

t = *time (minutes)*

$i = i^{th}$ *lane*

n = *total lanes*

$K(t)$ = *density at time t*

$\overline{L_V}$ = *average vehicle length (feet)*

L_D = *detection zone length (feet)*

$\%Occ_i(t) = i^{th}$ *lane percent occupancy at time t*

3.5.3 Traffic Data Classification

This study determined the volume of diverted traffic resulting from the CMS message by comparing the downstream through traffic volume based on the upstream volume during times when the CMS was used with the same time period under normal conditions. Therefore, data for two different conditions, the accident condition with CMS message and the normal condition, were collected at each study site. The data classification was based on the CMS message log information database from the MITSC. The CMS message log information database provides the time of day, operating CMS ID, message operator, displayed message text, accident or event location, and beginning and ending time the CMS message was activated. The accident and normal conditions were identified from this information.

3.5.3.1 Normal Condition Data Collection

Traffic flow on a section of a roadway varies from month to month and from day to day. However, during a specific time period if traffic flow is collected over days or months, the traffic pattern will be similar under normal conditions. Traffic patterns from Monday through Thursday tend to be similar but Friday has more traffic than other weekdays (Highway Capacity Manual 2000).

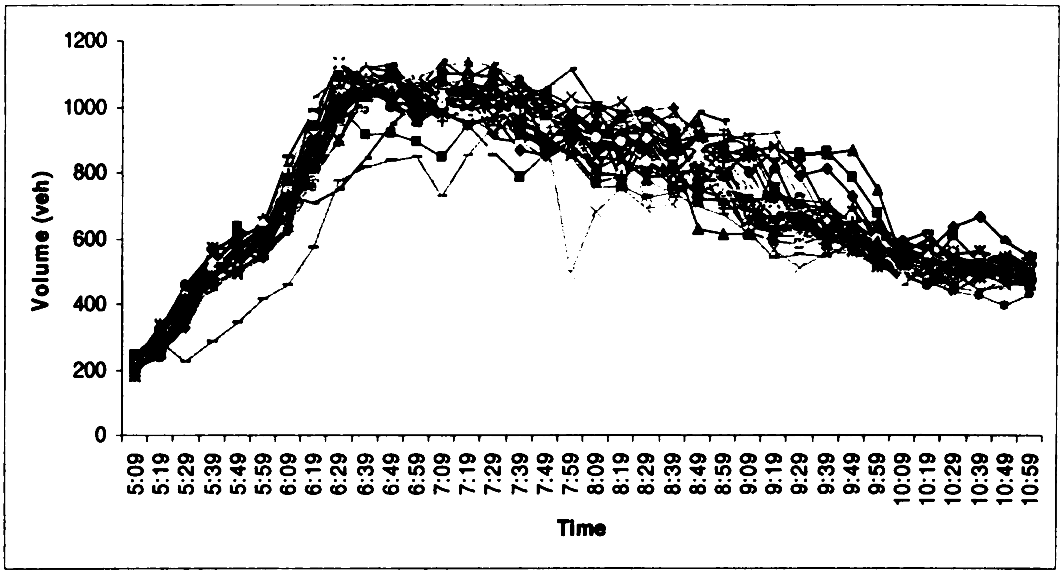
This study defined the normal condition as a weekday (Monday through Thursday) without accidents, events, construction, maintenance, or severe weather. The days which had no CMS message record on the CMS message log information database are considered normal condition days. However, when there was major construction (lane closed) or severe weather conditions (e.g., ice, fog, and thunder storm), these days were eliminated. Also, national holidays' such as New Year's Day, Independence Day, Labor Day, Thanksgiving and Christmas were not included as normal conditions.

3.5.3.2 Normal Condition Data Screening and Filtering

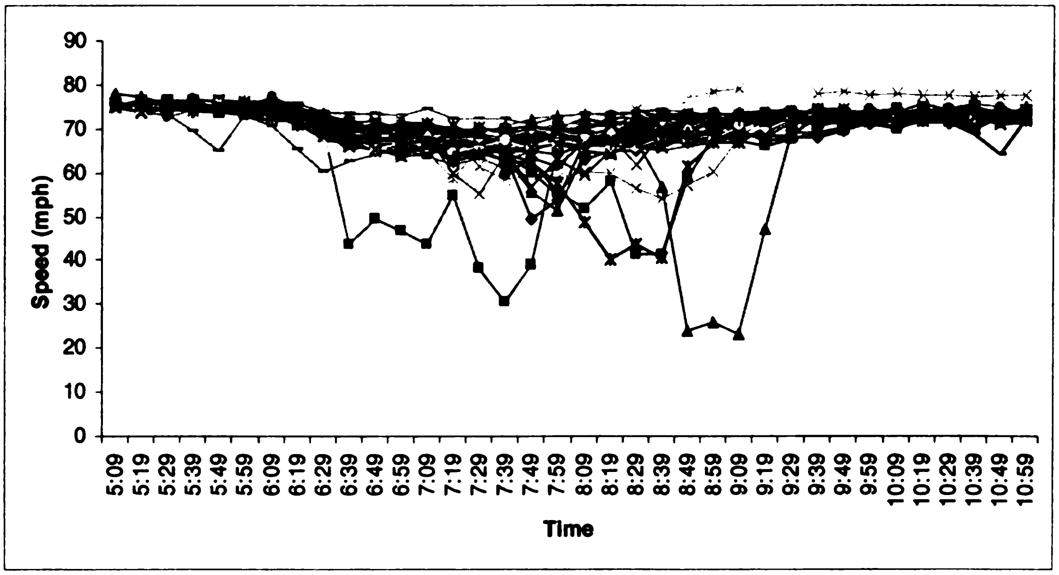
Even among the normal condition days as defined above, the database may include unannounced/undetected accident conditions or abnormal traffic patterns from a sports (or other) event. If these abnormal conditions are included in the normal condition days, it could bias the results. Therefore, this study screened the normal condition days. Each 10 minutes of data on the upstream and downstream volume and speed were plotted and examined for outliers. The days, which have an abnormal pattern of volume or speed either at the upstream or at the downstream detector stations were eliminated. Figure 3.3 (a) and (b) shows the volume and speed before filtering and figure 3.4 (a) and (b) shows these parameters after filtering. Table 3.4 shows the total number of days processed, and the filtered samples at each site.

Table 3. 4 Normal Condition Samples at the Study Site

Site	Site 1	Site 2	Site 3	Site 4	Site 5
Total normal condition samples based on CMS Message Log Information Database	44	50	40	55	40
Filtered AM-peak sample	35	38	34	43	34
Filtered Non-peak sample	33	36	33	42	24

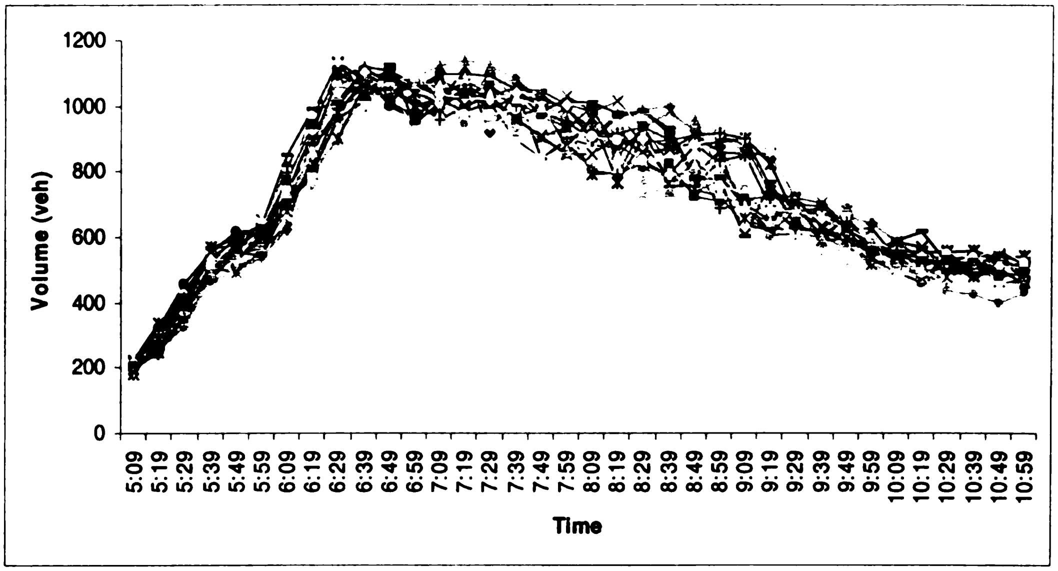


(a) Normal Condition Volume Profiles

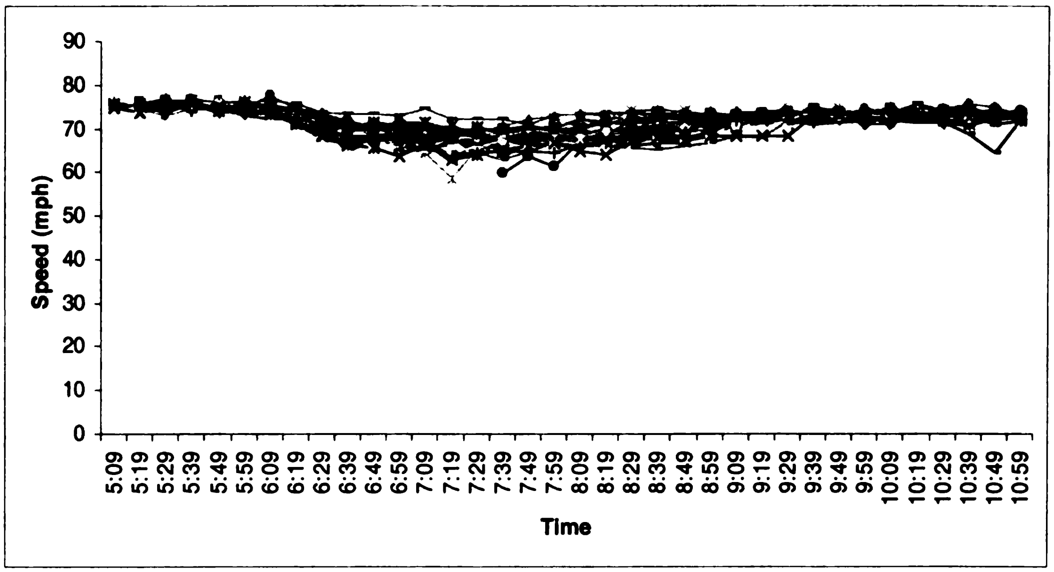


(b) Normal Condition Speed Profiles

Figure 3. 3 Normal Condition Profiles Before Filtering at Site 1



(a) Normal Condition Volume Profiles



(b) Normal Condition Speed Profiles

Figure 3. 4 Normal Condition Profiles After Filtering at Site 1

3.5.3.3 Accident Condition Data Collection

The literature review (Benson, 1996) reported that driver responses varied by message type. Drivers are more likely to divert for an "Accident" message than for a "Congestion ahead" message. It follows that the use of different types of accident related messages (such as disabled vehicle ahead, congestion ahead, freeway or lane closed, and ramp closed) might have differing affects on driver response. Therefore, this study analyzed data only at times when the CMS displayed "Accident" in the first line of the CMS text message. This study also used only accidents which occurred downstream of the downstream ILD but before the next interchange on the link.

3.5.3.4 Accident Condition Data Screening and Filtering

The objective of this study is to determine the effectiveness of CMS in diverting traffic by comparing the through traffic volume ratio between the upstream and downstream ILDs for accident conditions and normal conditions. If the CMS message does not influence the drivers' route, the through traffic volume ratio during the accident conditions will be similar to the same time period under normal conditions. However, if the CMS influences the drivers' route change behavior, the through traffic volume ratio will be reduced. In addition, if congestion from the accident extends upstream beyond the diversion interchange, the drivers' decision to divert to another route will be at least partially based on encountering the congestion as well as seeing the CMS. Thus, the database of accident days was filtered to remove all accidents where the congestion queue extends upstream of the diversion point. Table 3.5 shows the number of accident cases analyzed at each study site.

Table 3. 5 Accident Condition Samples at the Study Site

Site	Site 1	Site 2	Site 3	Site 4	Site 5
Accident Sample	18	8	13	8	13

3.6 Summary

The fundamental hypothesis for this research was that a CMS will not provide the same benefit at all locations and at all times of the day. However, the evaluation results from the literature were generally based on a particular location and time which may explain the inconsistent results reported in the literature. To address this problem, this research selected and analyzed the effectiveness at five CMS locations which have different geographic and traffic conditions.

CHAPTER 4

MEASUREMENT METHOD

4.1 Introduction

Previous research on driver behavior indicated that drivers have a propensity to use one regular route and are not likely to change their regular route under normal conditions. These studies also indicated that even though drivers are hesitant to change from their regular route in the absence of any information, some would use an alternate route if presented with CMS information. These conclusions, however, are based on drivers stated preference, and have not been fully evaluated with field data.

This study was conducted to identify and quantify the effectiveness of CMS using field traffic data. The measure of effectiveness (MOE) used in this study is the percent of traffic that diverts to an alternate route when presented with CMS information. The MOE is measured by comparing the ratio of downstream traffic volume to upstream traffic volume with and without CMS information. The variable used for this comparison is called the "diversion ratio".

The MOE was obtained by measuring the traffic volume at points upstream and downstream from an interchange immediately downstream from a CMS location. Volume data were collected and analyzed both when the CMS was actuated and at these same stations under normal conditions (CMS was not activated).

4.2 ILD Traffic Data Collection Method

When an accident occurs, drivers who are informed of the accident upstream of an interchange must decide to either stay on their current route or divert to an alternate route. However, the true diversion ratio can not be obtained simply by comparing the upstream and downstream traffic volumes during the time the CMS is activated for two reasons:

1) Vehicles still queued between the accident and the interchange when the message is discontinued would not be recorded at the downstream location, and these would be counted (incorrectly) as diverted vehicles; and
2) If the queue formed by the accident reaches the interchange, drivers may choose to take the alternate route because they observe the congestion rather than because they observed the CMS.

Therefore, it was necessary to develop a technique to identify all of the vehicles (and only those vehicles) that responded to the CMS by choosing an alternate route. Figure 4.1 shows a time-space vehicle trajectory diagram between an upstream and downstream Inductive Loop Detector (ILD) location. When the CMS provides accident information at the upstream location between T_1 and T_2, the first drivers who received the message and remained on the current route arrive at the downstream location between time T_3 (if the accident induced congestion has not reached the downstream ILD location) and T_4 (if the accident induced congestion has reached the downstream ILD location). The last drivers who observed the activated CMS message arrive at the downstream location between time T_5 (if all accident induced queued vehicles have been released) and T_6 (if not).

If the accident induced queue does not reach the downstream ILD location during the CMS message time period, the upstream vehicles will arrive at the downstream location with the same travel time as under normal conditions. However, if the accident induced queue reaches the downstream location, the travel time to reach the downstream ILD location is increased amount of time α or β. Therefore, an accurate count of traffic that passes the downstream location must consider the increased travel time resulting from the congestion.

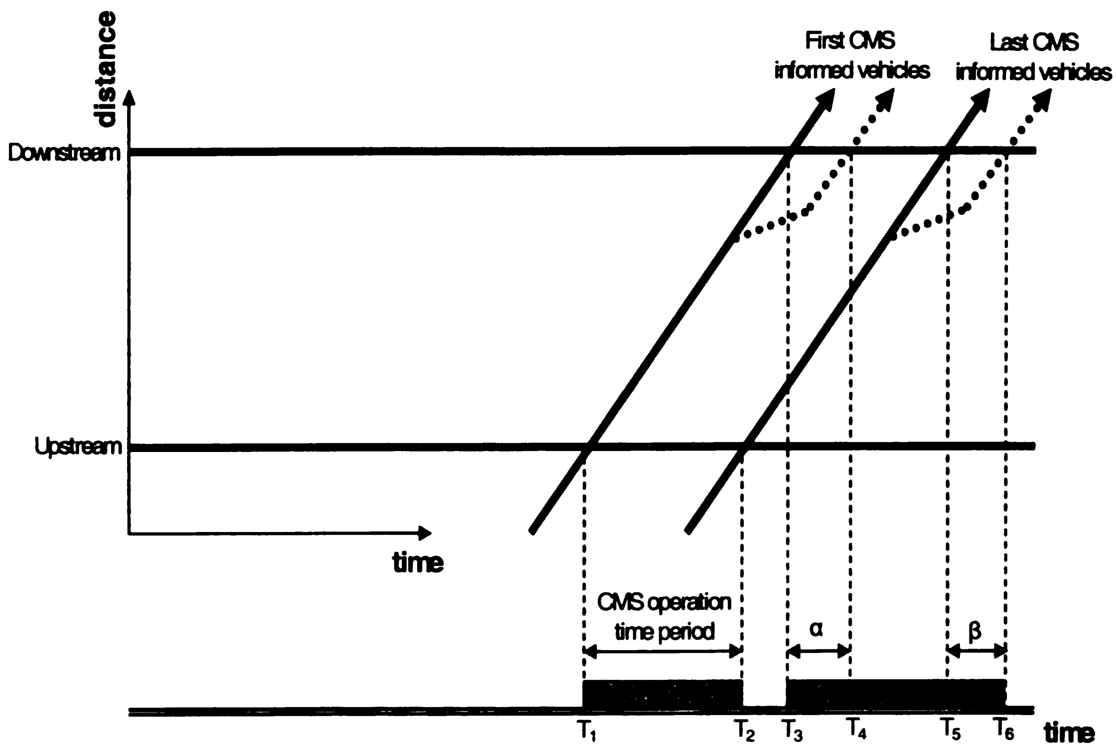


Figure 4.1 Vehicle Trajectory Time-Space Diagram

The equation used to determine the traffic volume at the upstream and downstream ILD are shown below,

Accident Condition

$$Q_{up\_acc} = \sum_{i=1}^{2} q_{up\_acc}(T_i)$$

$$Q_{down\_acc} = \sum_{i=3+\alpha}^{5+\beta} q_{down\_acc}(T_i)$$

Where,

i = time (minutes)

Q_{up_acc} = *total upstream volume during CMS accident message (vehicles)*

Q_{down_acc} = *total downstream volume during CMS accident message (vehicles)*

$q_{up\_acc}(T_i)$ = *accident condition upstream volume at time T_i (vehicles/minute)*

$q_{down\_acc}(T_i)$ = *accident condition downstream volume at Time T_i (vehicles/minute)*

α, β = *congestion delay time (minutes)*

Normal Conditions

$$Q_{up\_nor}(j) = \sum_{i=1}^{2} q_{up\_nor}(T_i)$$

$$Q_{down\_nor}(j) = \sum_{i=3}^{5} q_{down\_nor}(T_i)$$

Where,

i = time (minutes)

j = a normal condition day j

$Q_{up\_nor}(j) =$ *total upstream volume during normal condition day j (vehicles)*

$Q_{down\_nor}(j) =$ *total downstream volume during normal condition day j (vehicles)*

$q_{up\_nor}(T_i)$ *=normal condition upstream volume at time T_i (vehicles/minute)*

$q_{down\_nor}(T_i)$ *=normal condition downstream volume at time T_i (vehicles/minute)*

Diversion Ratio Measurement

The diversion ratio was calculated as:

$$Exp\_Q_{down\_acc} = \frac{Q_{down\_nor}(j) \times Q_{up\_acc}}{Q_{up\_nor}(j)}$$

$$Exp\_Q_{down\_acc} - \mathrm{Re}\,al\_Q_{down\_acc} = diverted\ traffic\ volume$$

$$\%\ diversion\ ratio = \frac{diverted\ traffic\ volume}{Exp\_Q_{down\_acc}}$$

Where,

$Exp\_Q_{down\_acc} =$ *expected total downstream volume during accident condition with CMS message (vehicles)*

$\mathrm{Re}\,al\_Q_{down\_acc} =$ *real total downstream volume during accident condition with CMS message (vehicles)*

$Q_{up\_acc} =$ *total upstream volume during CMS accident message (vehicles)*

$Q_{up\_nor}(j) =$ *total upstream volume during normal condition day j (vehicles)*

4.3 Travel Time Measurement Method

The time intervals T_3 - T_1 and T_5 - T_2 depend on the speed of traffic and the distance between the upstream and downstream ILDs. Since continuous speed data over this distance is not available, the travel time must be estimated from the speed data collected at the two ILD locations. When traffic demand approaches or exceeds reduced system capacity resulting from the accident, congestion is generated and travel time increases.

From the minute by minute speed data collected at the upstream and downstream ILD locations, link travel time must be estimated. Depending on the downstream traffic conditions and the ILD locations shown in Figure 4.2, travel time was estimated as follows:

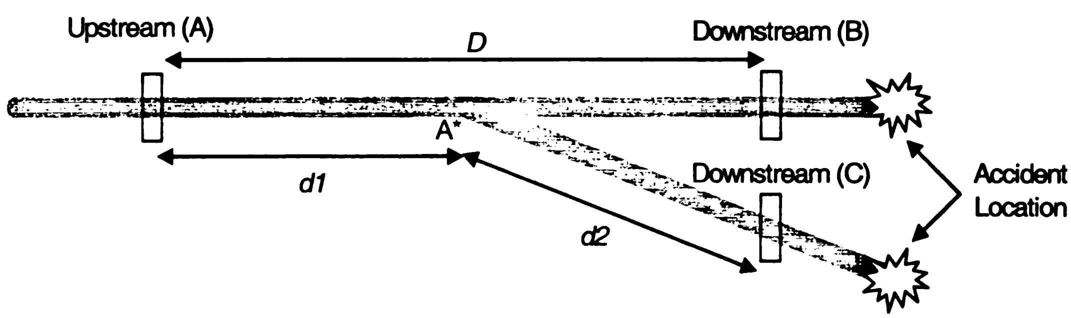


Figure 4.2 ILD Location Diagram

<u>Case 1: No Accident Induced Congestion Exists at the Downstream Location</u>

a) Link Travel Time $\overline{AB}$

$$\mu_{up\_A}(t_i) \cong \mu_{down\_B}(t_{i+\alpha}) \geq design\ speed$$

$$k = \frac{D}{\mu_{up\_A}(t_i)}$$

Then

$$LT_{AB} = \frac{D}{\mu_{up\_A}(t_i)}$$

b) Link Travel Time $\overline{AC}$

$$\mu_{up\_A}(t_i) \cong \mu_{down\_C}(t_{i+\alpha}) \geq design\ speed$$

$$k = \frac{d_1}{\mu_{up\_A}(t_i)}$$

Then

$$LT_{AC} = \frac{d_1}{\mu_{up\_A}(t_i)} + \frac{d_2}{\mu_{down\_C}(t_{i+k})}$$

Where,

i = time (minute)

D = link distance $\overline{AB}$ (mile)

d_1 = link distance $\overline{AA^*}$ (mile)

d_2 = link distance $\overline{A^*B}$ (mile)

$\mu_{up\_A}(t_i)$ = upstream ILD A vehicle speed at time i (mph)

$\mu_{down\_B}(t_i)$ = downstream ILD B vehicle speed at time i (mph)

$\mu_{down\_C}(t_i)$ = downstream ILD C vehicle speed at time i (mph)

LT_{AB} = link travel time $\overline{AB}$ (minute)

LT_{AC} = link travel time $\overline{AC}$ (minute)

Case 2: Accident Induced Congestion at Downstream Location

a) Link Travel Time $\overline{AB}$

$$\mu_{up\_A}(t_i) \neq \mu_{down\_B}(t_{i+\alpha})$$

$$k = \frac{D}{\mu_{up\_A}(t_i)}$$

$$\mu_{up\_A}(t_i) \geq design\ speed$$

$$\mu_{down\_B}(t_{i+\alpha}) = congestion\ delay\ speed$$

Then

$$LT_{AB} = \frac{D-QD}{\mu_{up\_A}(t_i)} + \frac{QD}{\mu_{down\_B}(t_{i+k})}$$

a) Link Travel Time $\overline{AC}$

$$\mu_{up\_A}(t_i) \neq \mu_{down\_C}(t_{1+\alpha})$$

$$k = \frac{d_1}{\mu_{up\_A}(t_i)} + \frac{d_2}{\mu^*_{down\_C}(t_i)}$$

$$\mu_{up\_A}(t_i) \geq design\ \ speed$$

$$\mu^*_{down\_C}(t_i) = design\ \ speed$$

$$\mu_{down\_C}(t_{i+\alpha}) = congestion\ \ delay\ \ speed$$

Then

$$LT_{AC} = \frac{d_1}{\mu_{up\_A}(t_i)} + \frac{d_2 - QD}{\mu^*_{down\_C}(t_i)} + \frac{QD}{\mu_{down\_C}(t_{i+k})}$$

Where,

i = *time (minute)*

D = *link distance* $\overline{AB}$ *(mile)*

d_1 = *link distance* $\overline{AA^*}$ *(mile)*

d_2 = *link distance* $\overline{A^*B}$ *(mile)*

QD = *congestion queue distance*

$\mu_{up\_A}(t_i)$ = *upstream ILD A vehicle speed at time i (mph)*

$\mu_{down\_B}(t_i)$ = *downstream ILD B vehicle speed at time i (mph)*

$\mu_{down\_C}(t_i)$ = *downstream ILD C vehicle speed at time i (mph)*

LT_{AB} = *link travel time* $\overline{AB}$ *(minute)*

LT_{AC} = *link travel time* $\overline{AC}$ *(minute)*

4.4 Queue Distance (QD) Estimation Method

When a sudden reduction in capacity occurs due to an accident, the flow on the road suddenly changes from volume (q_1) to a lower value of volume (q_2), with a corresponding change in density from k_1 to a higher value k_2. When congestion exists, the density on the road is relatively large and the speed of the vehicles is relatively low. A shockwave (u_w) is generated as a result of this change in conditions. When the density downstream is lower than upstream (u_w is positive), we have a diffusion of flow similar to that observed when a queue is discharging. When the downstream density is higher than upstream (u_w is negative), then shockwaves are generated and queues move in an upstream direction.

The shockwave speed can be estimated using the volume and density upstream (inflow) and downstream (outflow) by the following equation. The congestion distance at any time (T_i) can be obtained from the shockwave speed:

$$u_w = \frac{q_{down} - q_{up}}{k_{down} - k_{up}}$$

Where,

u_w = *shockwave speed (mph)*

q_{up} = *upstream (inflow) volume*

k_{up} = *upstream(inflow) density*

q_{down} = *downstream (outflow) volume*

k_{down} = *downstream (outflow) density*

On an uninterrupted segment of roadway for which a flow-density relationship is known, the congestion distance is equal to $\mu_w(t)$. However, in this study, the ILDs are not located on an uninterrupted segment of roadway, since there is an interchanges and entering/exit ramps between the two locations; and, for a site which has an alternate route, the ILDs may not be located on the same roadway. Therefore, the upstream and downstream ILD locations may have different flow-density relationships from each other. The volume profiles for the upstream and downstream ILDs at Site 1 under normal condition are shown in Figure 4.3.

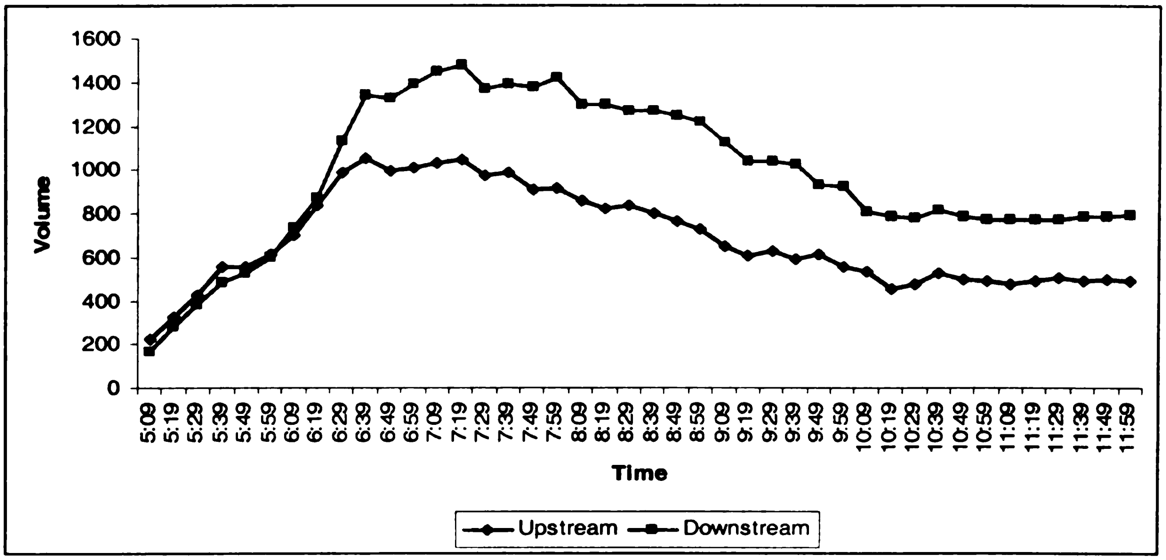
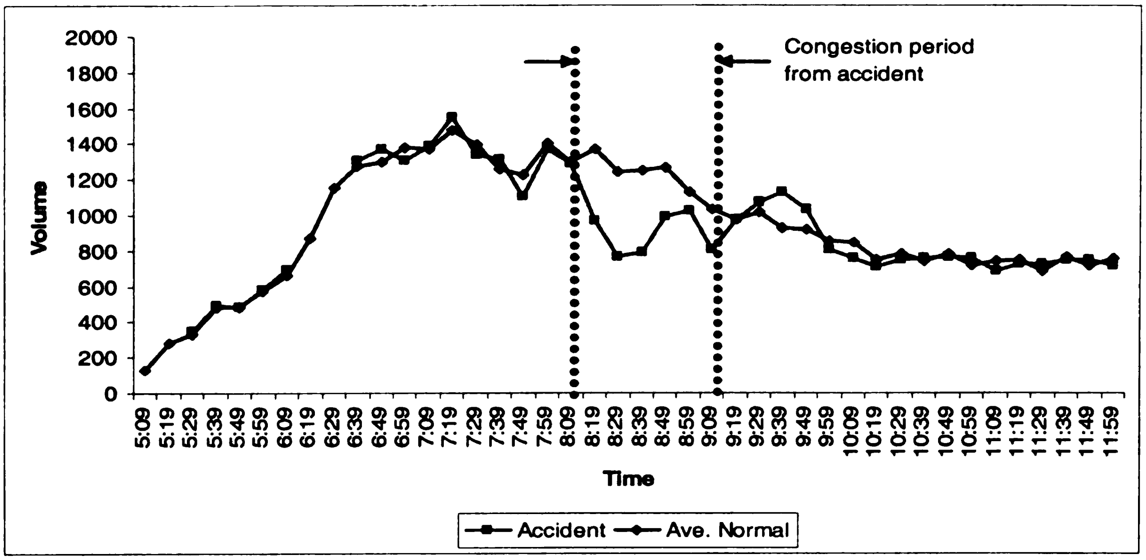
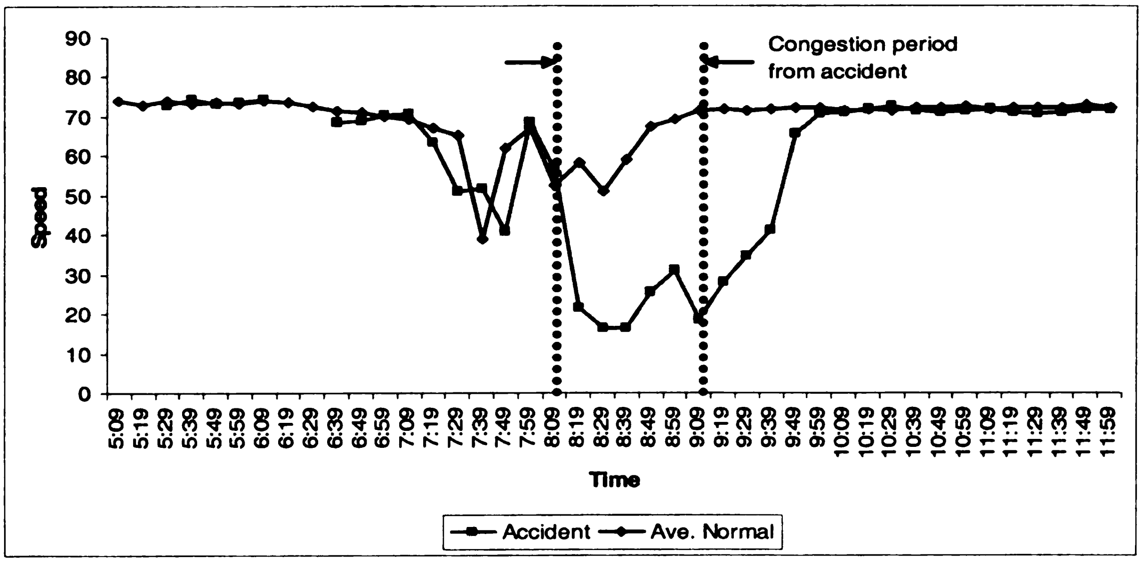


Figure 4.3 Upstream and Downstream Volume Profile at Site 1

Therefore, it is not appropriate to use the upstream ILD traffic data as the inflow traffic for measuring shockwave speed during the accident time period. Instead of using the upstream flow-density data as inflow traffic at the downstream location during an accident condition, this study used the flow-density that occurs under normal conditions at the downstream ILD as the inflow traffic. Figure 4.4 shows volume and speed profiles at the downstream location for an accident condition and the average normal condition. As can be seen in the figure 4.4, the volume and speed are similar between the accident and average normal condition except during the congestion time period resulting from the accident. Therefore, it can be assumed that if the accident had not occurred, the inflow traffic of volume and speed during the accident time period would be similar to the average normal conditions. Using this assumption, the congestion distance at any time following the accident occurrence can be calculated.



(a) Volume Profile



(b) Density Profile

Figure 4.4 Volume and Density Profiles at Site 1 Downstream Location (I-696 EB)

As shown in Figure 4.5, the shockwave speed was calculated for three different conditions: (a) a backward shockwave which occurs as a result of the normal flow-density conditions encountering the flow-density conditions of the queue formed as a result of the accident, (b) a backward shockwave resulting from the flow-density conditions that exist with some traffic diverted in response to the CMS encountering the flow-density condition of this queue, and (c) a forward shockwave during the queue dissipation period.

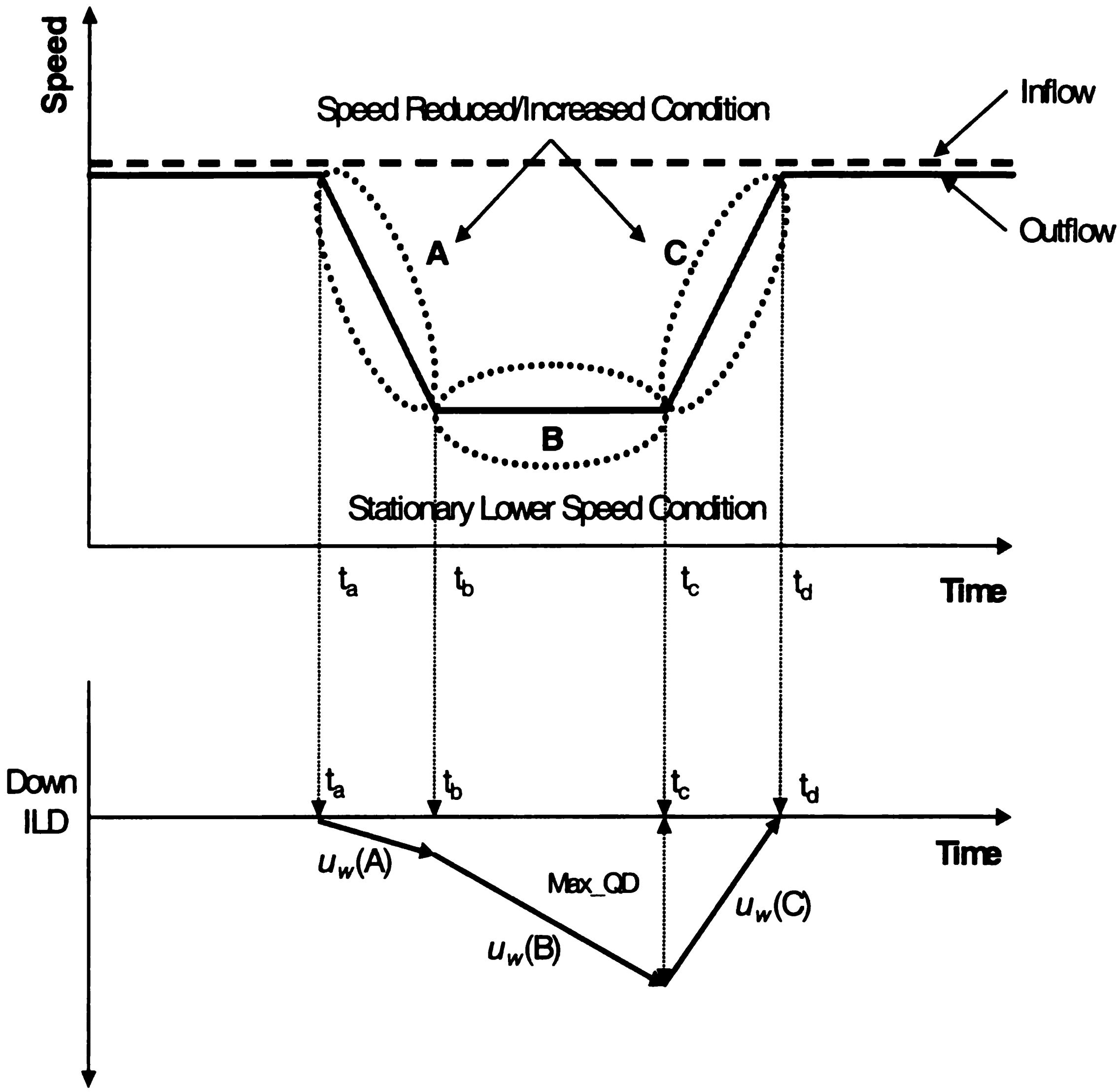


Figure 4.5 Shockwave Speed Diagram

The shockwave speed and congestion distance were estimated using the equations below:

$$\bar{q}_{in}(t_{n-m}) = \frac{\sum_{i=n}^{m} q_{in}(t_i)}{t_m - t_n} \qquad \bar{k}_{in}(t_{n-m}) = \frac{\sum_{i=n}^{m} k_{in}(t_i)}{t_m - t_n}$$

$$\bar{q}_{out}(t_{n-m}) = \frac{\sum_{i=n}^{m} q_{out}(t_i)}{t_m - t_n} \qquad \bar{k}_{out}(t_{n-m}) = \frac{\sum_{i=n}^{m} k_{out}(t_i)}{t_m - t_n}$$

$$u_w(A) = \frac{60}{number\ of\ lanes} \times \frac{\bar{q}_{out}(t_{a-b}) - \bar{q}_{in}(t_{a-b})}{\bar{k}_{out}(t_{a-b}) - \bar{k}_{in}(t_{a-b})}$$

$$u_w(B) = \frac{60}{number\ of\ lanes} \times \frac{\bar{q}_{out}(t_{b-c}) - \bar{q}_{in}(t_{b-c})}{\bar{k}_{out}(t_{b-c}) - \bar{k}_{in}(t_{b-c})}$$

$$u_w(C) = \frac{60}{number\ of\ lanes} \times \frac{\bar{q}_{out}(t_{c-d}) - \bar{q}_{in}(t_{c-d})}{\bar{k}_{out}(t_{c-d}) - \bar{k}_{in}(t_{c-d})}$$

$$QD(A) = u_w(A) \times 1.47 \times 60 \times (t_b - t_a)$$
$$QD(B) = u_w(B) \times 1.47 \times 60 \times (t_c - t_b)$$
$$QD(C) = u_w(C) \times 1.47 \times 60 \times (t_d - t_c)$$

$$Max\_QD = QD(A) + QD(B)$$

Where,

i = time (minute)

$q_{in}(t_i)$ = *inflow traffic volume at time t_i (veh/min)*

$k_{in}(t_i)$ = *inflow traffic density at time t_i (veh/mile)*

$q_{out}(t_i)$ = *outflow traffic volume at time t_i (veh/min)*

$k_{out}(t_i)$ = *outflow traffic density at time t_i (veh/mile)*

$\bar{q}_{in}(t_{n-m})$ = *average inflow traffic volume during time n - m (veh/min)*

$\bar{k}_{in}(t_{n-m})$ = *average inflow traffic density during time n - m (veh/mile)*

$\bar{q}_{out}(t_{n-m})$ = *average outflow traffic volume during time n - m (veh/min)*

$\bar{k}_{out}(t_{n-m})$ = *average outflow traffic density during time n - m (veh/mile)*

$u_w(A)$ = *shockwave speed in group A traffic(mph)*

$u_w(B)$ = *shockwave speed in group B traffic (mph)*

$u_w(C)$ = *shockwave speed in group C traffic (mph)*

QD (A) = congestion queue distance during condition A (feet)

QD (B) = congestion queue distance during condition B (feet)

QD (C) = congestion queue distance during condition C (feet)

Max_QD = maximum congestion queue distance (feet)

4.5 Summary

Using data from the upstream and downstream ILD data under normal conditions, the ratio of these two volumes can be used to estimate the number of vehicles that would be expected to pass the downstream ILD under various conditions using upstream ILD data from days when an accident occurred and the CMS was activated. The equations developed in this section are used to estimate the number of vehicles that actually passed the downstream ILD. The difference between the expected number of vehicles and the actual number of vehicles that passed the downstream ILD is a measure of the traffic diverted to an alternate route due to the CMS.

CHAPTER 5

DATA ANALYSIS AND RESULTS

5.1 Introduction

These analyses were performed to accomplish three primary goals: first, to measure the route diversion effectiveness of CMS; second, to determine the sensitivity of the diversion factors which exert the greatest effect on a drivers' route decision; and last, to identify the characteristics of locations where the CMS will be most effective. To accomplish this, the diversion ratio for each of the five sites was determined under several conditions and the influence of factors which affect the diversion ratio were then determined from these results.

5.2 Sensitivity Analysis Factors

5.2.1 Familiarity and Time Constraint Sensitivity

From the literature, it was determined that a drivers' route diversion is influenced by their familiarity with the street network and their time constraints. The drivers who are familiar with an area are more likely to divert to an alternate route. Also, drivers who have time pressure are more likely to switch their route.

In general, in the AM-peak period there is a larger percentage of home-to-work drivers in the traffic stream than the same location at other time periods. This group of drivers is more willing to divert from their usual route to an alternate route because of two factors: they are likely to be familiar with alternative routes, and they are under time pressure. In the non-peak period there are a larger proportion of shopping trips and non-work trips, and past research has found that these trips are less influenced by these two factors. The diversion behavior of drivers is hypothesized to be significantly different between these two time periods when the same CMS message is displayed. To test this hypothesis, this study compares the diversion ratio during the AM-peak period (06:00 – 09:00) with the Non-peak period (10:00 – 16:00) to determine the effect to these two factors.

5.2.2 Visual Sensitivity

Previous surveys reported a relationship between drivers' route diversion behavior and traffic congestion. Most of the results indicated that drivers are more likely to change routes when they observe traffic congestion than when they are simply informed of the fact that it exists. To test this hypothesis, this study determined the difference in the diversion ratio when drivers encounter the queue formed from the incident and when they only observe the CMS. To do this, the models to estimate the length of the congestion queue for each accident were developed, and the incidents were classified into two groups: an accident condition in which the congestion moves upstream beyond the diversion point and an accident condition where drivers could not observe the congestion prior to the diversion point.

5.2.3 Traffic Condition Sensitivity

Previous surveys also reported that drivers expressed a higher willingness to divert if an accident occurs at a time and location where recurring congestion exists. The third sensitivity analysis compares the change in the route diversion ratio on routes with and without recurring congestion.

5.2.4 Geographical Location Sensitivity

The final sensitivity analysis compared the diversion ratio base on the geographic location. Some sites have an alternate freeway route, while other locations have only arterial road alternate routes. Three sites (Site 1, Site 2 and Site 3) have freeway-based alternate routes. The remaining two (Site 4 and Site 5) only have exits to arterial roads. This study examined the diversion ratio between locations with and without freeway-based alternate routes.

5.3 Analysis of the CMS Effect at Site 1

5.3.1 Description of Site 1

Site 1 is located at the junction of I-96(I-275)/I-696 on the Novi/Farmington Hills boundary in southern Oakland County. Both I-96 and I-696 are major east/west freeways in the Metropolitan Detroit area. CMS 23 provided information on downstream traffic conditions to eastbound drivers in advance of an interchange which provides three alternate routes: M-5 south-east bound, I-96(I-275) southbound and I-696 eastbound. I-96(I-275) and I-696 have a 70mph speed limit and provide nearly equal travel distances to the center of downtown Detroit. M-5 provides the shortest distance to the center of downtown; however, it has a 65mph speed limit before the junction at Grand River Avenue and a speed limit of 45mph from there to the center of downtown.

As shown in Figure 5.1, traffic data are collected at three ILD locations. The upstream ILD (A) was located on I-96 west of Novi Road. The two downstream ILD used at this site are located on I-696 east of Farmington Road (B), and on I-275 south of Grand River Avenue (C). The CMS provides information on accidents that occur on I-696, I-96 (I-275) or M-5 downstream of the interchange. The downstream section of I-696 has 20 - 30 minutes of recurring congestion during the AM-peak period, but the downstream sections of I-96 (I-275) and M-5 do not experience recurring congestion.

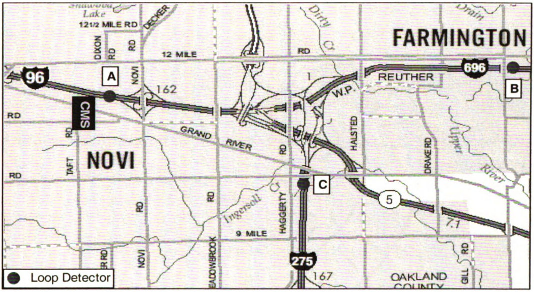


Figure 5.1 Site 1 Location

Data on eighteen accidents were collected at site 1. Table 5.1 shows the date, time, and location of each of these accidents. The congestion distance for each accident case was calculated using the queue length measurement technique described in Chapter 4.

From the data collection procedure in chapter 3, filtered normal condition sample data for each accident case was constructed.

There was a construction project on this freeway segment in July, August, and September 2001. Among the collected accident cases, four accidents (cases 1, 2, 6, and 17) occurred during the construction period. The normal condition sample data used as a comparison for these four accidents were collected during the construction time period.

Table 5. 1 Descriptions of Collected Accident Conditions with CMS Message at Site 1

Case	Accident Date	CMS Operation Time	CMS Accident Message	Congestion Distance	Normal Condition Sample
1	07-23-01	08:11 – 09:11	Accident I-696 EB at Middlebelt Road.	Max_QD > DP	4
2	07-25-01	08:52 – 09:52	Accident I-696 EB at Orchard Lake Road	Max_QD < DP	4
3	11-14-01	07:20 – 08:20	Accident I-696 EB at Telegraph Road	Max_QD < DP	35
4	07-29-02	07:17 – 08:17	Accident I-696 EB before Telegraph Road	Max_QD > DP	35
5	11-20-02	07:18 – 08:18	Accident I-696 EB at Orchard Lake Road	Max_QD < DP	35
6	09-24-01	07:20 – 08:20	Accident I-275 SB at 5 Mile Road	Max_QD < DP	4
7	11-27-01	06:54 – 08:54	Accident I-275 SB at 6 Mile Road	Max_QD > DP	35
8	02-11-02	07:24 – 08:24	Accident I-275 SB at 5 Mile Road	Max_QD < DP	35
9	02-19-02	07:39 – 08:39	Accident I-275 SB at 6 Mile Road	Max_QD > DP	35
10	07-16-02	07:50 – 08:50	Accident I-275 SB at 7 Mile Road	Max_QD > DP	35
11	08-29-02	07:50 – 08:50	Accident I-275 SB at 6 Mile Road	Max_QD < DP	35
12	12-05-02	07:58 – 08:58	Accident I-275 SB at 6 Mile Road	Max_QD < DP	35
13	11-19-01	13:46 – 14:46	Accident I-696 EB before Farmington Hill Road	Max_QD < DP	33
14	03-21-02	11:20 – 12:20	Accident I-696 EB at Orchard Lake Road	Max_QD < DP	33
15	04-18-02	15:14 – 16:14	Accident I-696 EB before Middlebelt Road	Max_QD < DP	33
16	07-30-02	14:15 – 16:15	Accident I-696 EB before Inkster Road	Max_QD < DP	33
17	09-04-01	14:12 – 15:12	Accident I-275 SB before 5 Mile Road	Max_QD < DP	4
18	12-04-02	15:36 – 16:36	Accident I-275 SB at 8 Mile Road	Max_QD < DP	33

Previously, it was indicated that traffic flow at a section of a roadway varies from day to day, however a certain time period of flow patterns and volumes are similar to each other. Even though an accident occurred at a downstream location, traffic flow at an upstream would be similar as the same time period under normal conditions. Figure 5.2 shows the upstream traffic volumes of the eighteen accident cases and the related normal conditions at site 1.

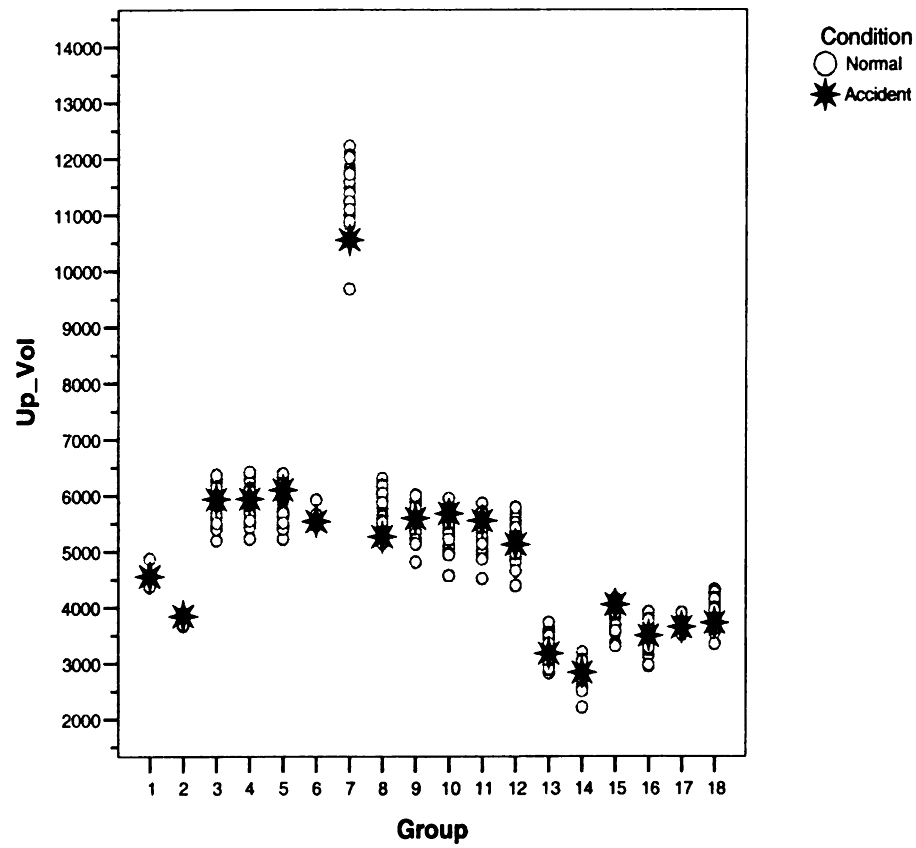


Figure 5. 2 Upstream Volume Distribution at Site 1

It is shown that the upstream volumes of all eighteen accident cases are similar to the related normal condition. Therefore, it is expected that if the CMS has not effected drivers' route diversion behavior, the through traffic volume ratio should be similar to the normal conditions. Figure 5.3 helps to visualize the distribution of the downstream to upstream volume ratio between accident and the related normal conditions.

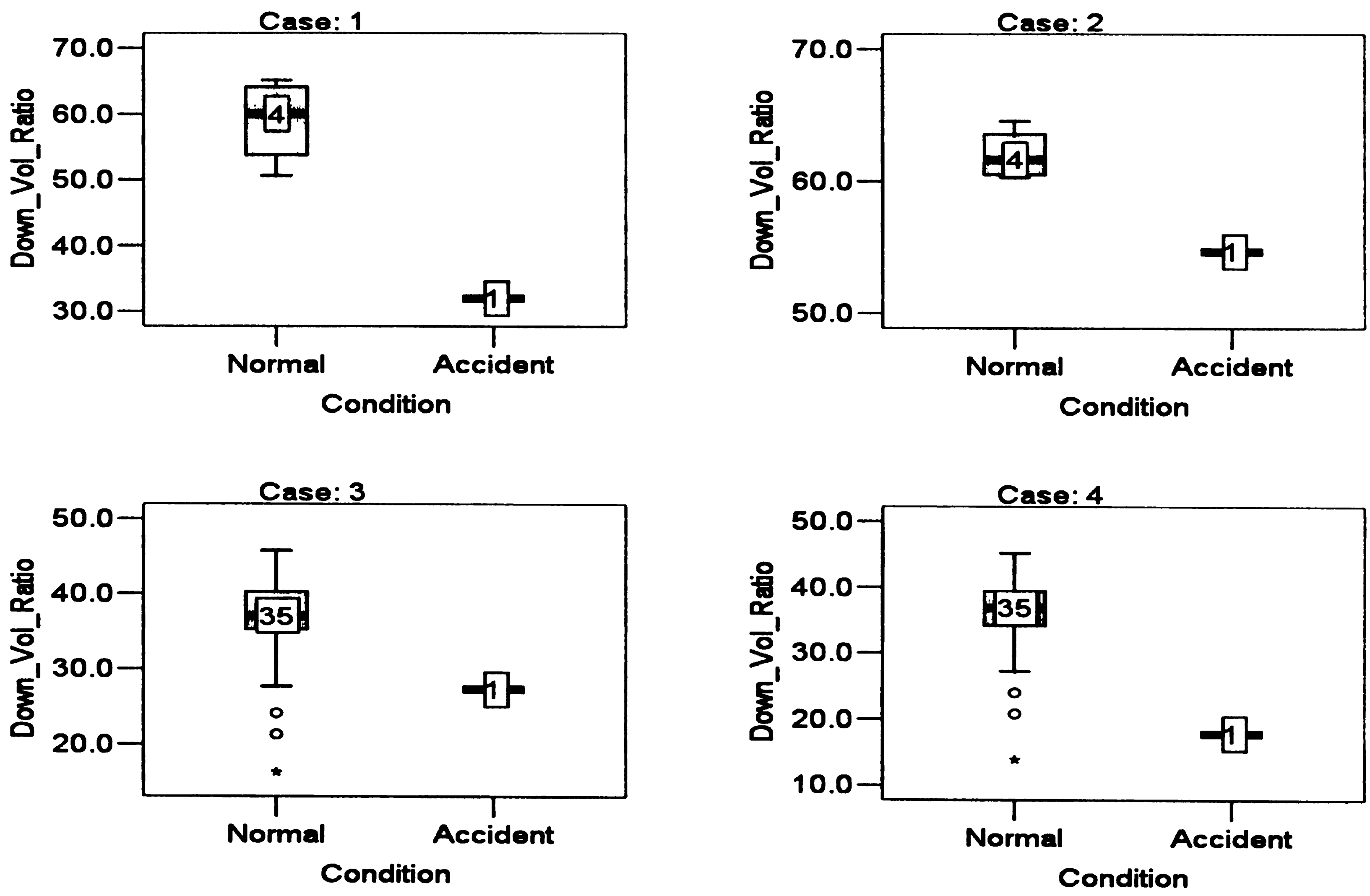


Figure 5.3 Downstream Volume Ratio Comparisons

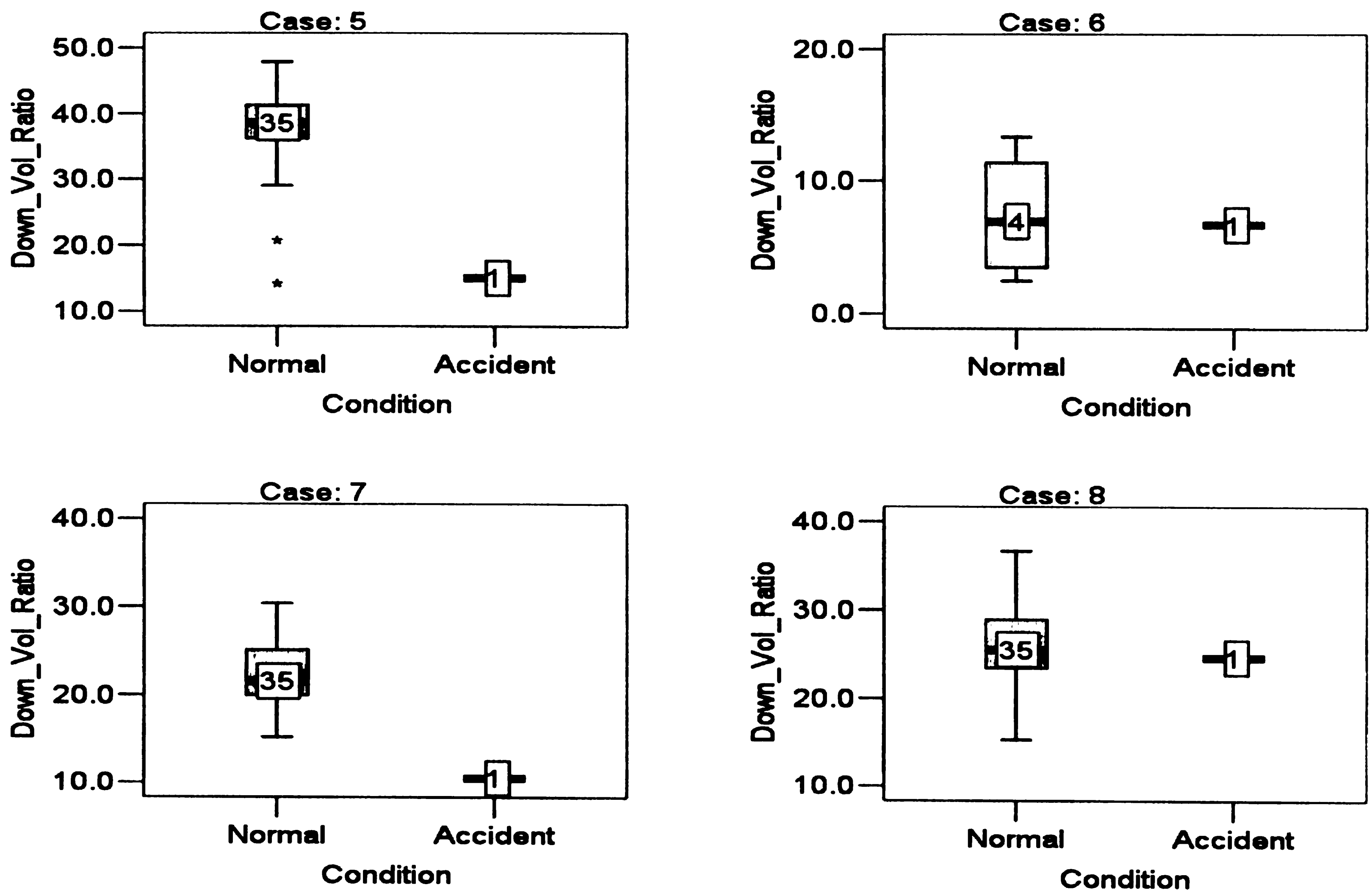


Figure 5.3 Downstream Volume Ratio Comparisons (Continued)

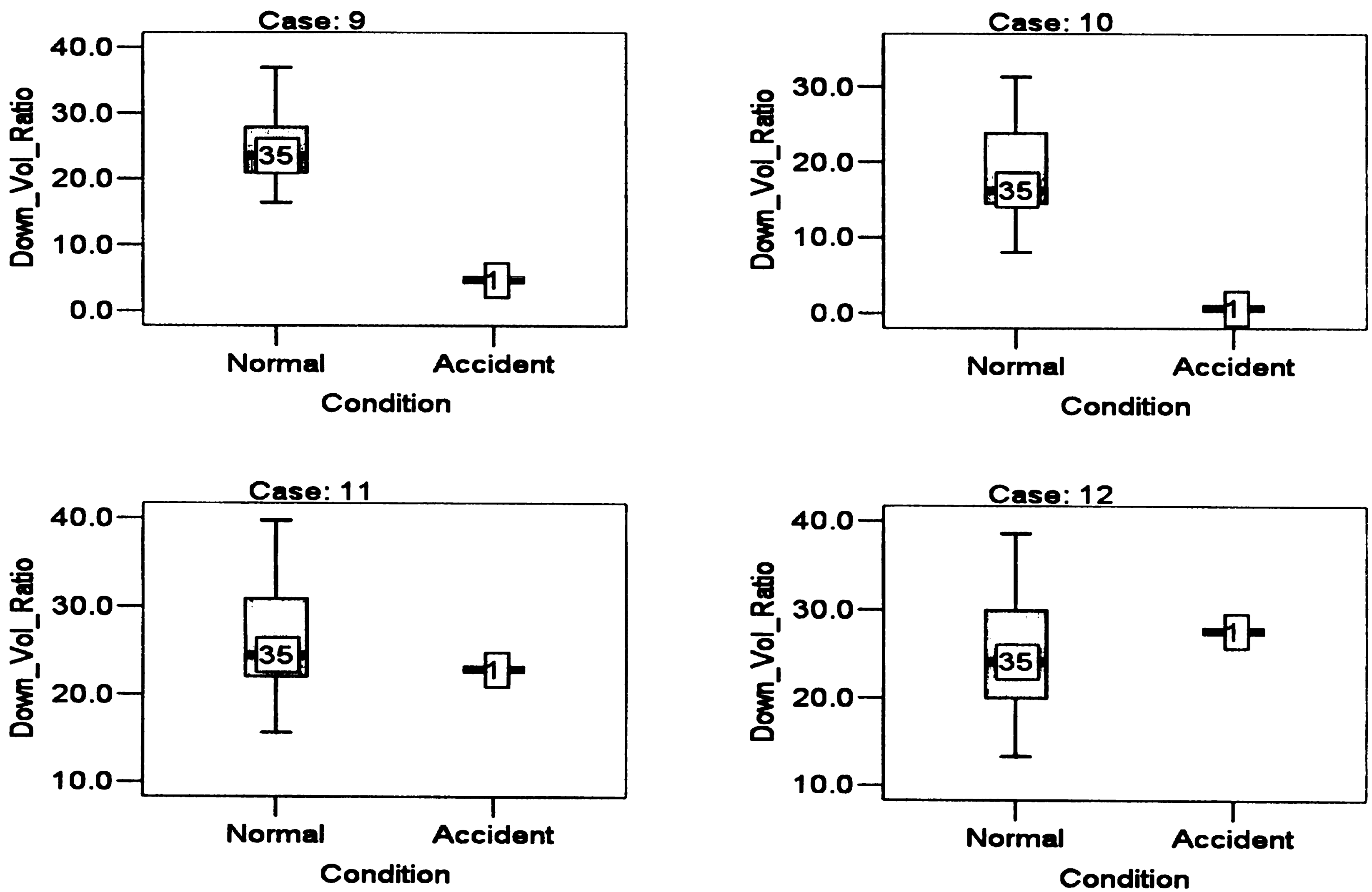


Figure 5.3 Downstream Volume Ratio Comparisons (Continued)

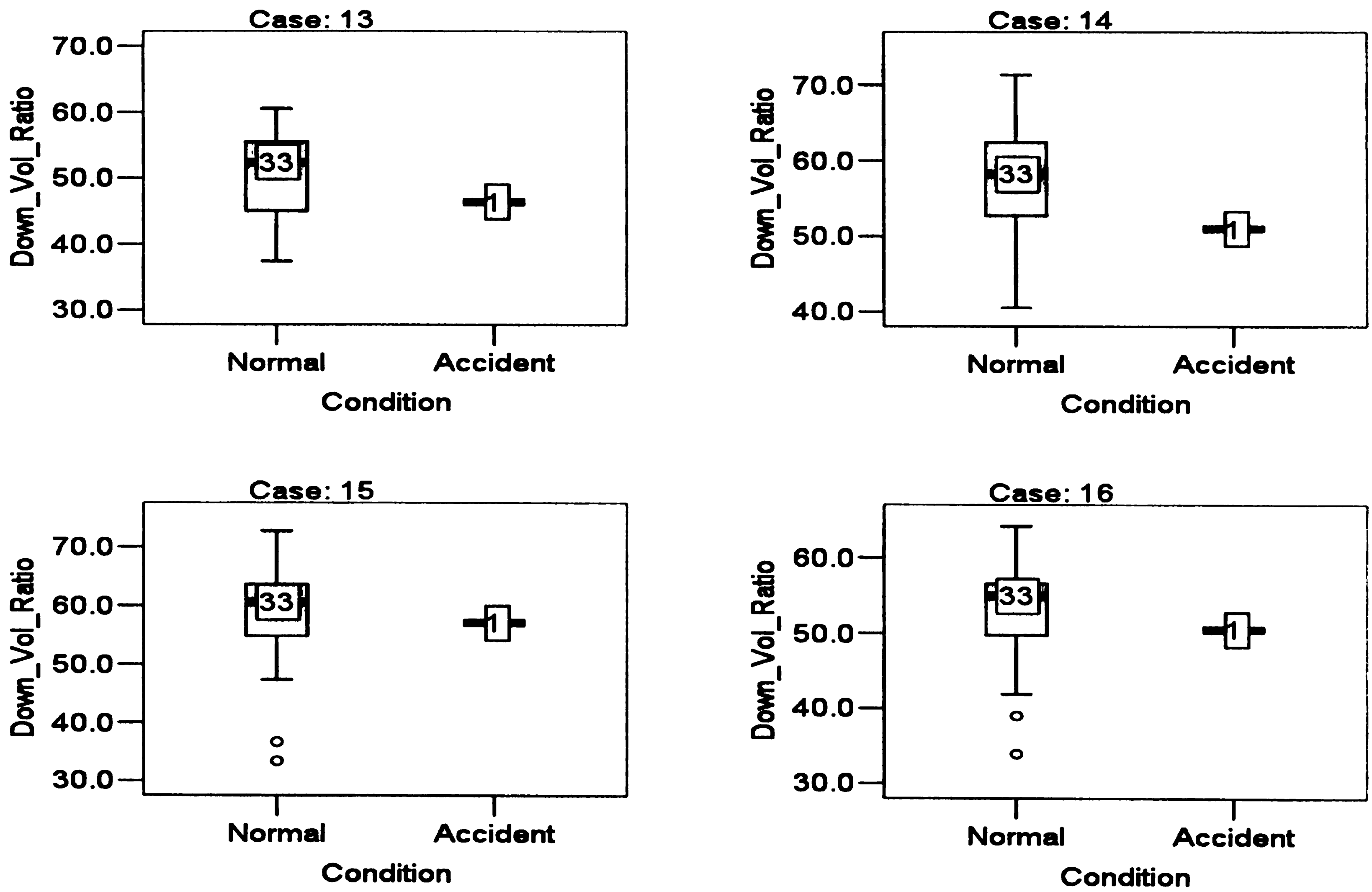


Figure 5.3 Downstream Volume Ratio Comparisons (Continued)

Figure 5.3 Downstream Volume Ratio Comparisons (Continued)

From Figure 5.3, it is shown that the accident conditions of downstream volume ratio during the AM-peak period are outside of the lower boundary of the box (represents the 25th percentile limits of the ratio) from the normal conditions while the accident conditions in the non-peak period are inside the lower boundary of the box.

5.3.2 Diversion Ratio Analysis

As defined in Chapter 4, the difference between the expected and the actual downstream volumes resulting from the CMS display were considered as diverted traffic. Table 5.2 shows the CMS operation time period for each of the crashes along with the message, the queuing conditions and the number of days in the normal operation sample.

Table 5.2, lists the upstream and downstream volume for each case along with the diversion ratio. The diversion ratio ranges between -1.96% and 16.85%. Because there are daily variations in the ratio of the downstream volume to the upstream volume, a statistical test was conducted to determine the significance of the change in the downstream traffic volume on the accident date. A t-Test was conducted using the percent reduction from each normal condition day as an independent sample point. The null hypothesis is that there is no reduction on these days;

$$H_0 : d = 0$$
$$H_a : d \neq 0 \text{ or } d > 0$$

Where d is the diversion ratio on the accident date

Table 5. 2 Accident and Related Normal Condition Traffic Volume at Site 1

Case	Condition	Upstream Volume	Downstream Volume	Expected Downstream Volume	Downstream Volume Reduction (Exp-Acc)	% Reduction
Case 1	Normal	4551	7224			
	Accident	4559	6018	7237	1219	16.85%
Case 2	Normal	3799	6155			
	Accident	3846	5949	6232	283	4.53%
Case 3	Normal	5789	7895			
	Accident	5934	7552	8095	543	6.71%
Case 4	Normal	5828	7882			
	Accident	5941	7003	8037	1034	12.86%
Case 5	Normal	5814	8008			
	Accident	6100	7022	8404	1382	16.44%
Case 6	Normal	5638	6050			
	Accident	5539	5909	5951	42	0.75%
Case 7	Normal	11344	13860			
	Accident	10555	11666	12902	1236	9.58%
Case 8	Normal	5735	7217			
	Accident	5264	6561	6630	69	1.04%
Case 9	Normal	5539	6881			
	Accident	5595	5858	6958	1099	15.79%
Case 10	Normal	5407	6396			
	Accident	5679	5718	6729	1011	15.02%
Case 11	Normal	5326	6708			
	Accident	5549	6816	6998	182	2.60%
Case 12	Normal	5232	6537			
	Accident	5125	6542	6416	-126	-1.96%
Case 13	Normal	3304	4952			
	Accident	3174	4647	4767	120	2.52%
Case 14	Normal	2751	4326			
	Accident	2835	4281	4459	178	3.99%
Case 15	Normal	3814	6026			
	Accident	4050	6362	6406	44	0.69%
Case 16	Normal	3515	5356			
	Accident	3492	5256	5330	74	1.39%
Case 17	Normal	3703	5058			
	Accident	3643	4818	4981	163	3.27%
Case 18	Normal	3905	6543			
	Accident	3722	6260	6245	-15	-0.24%
Average	**Normal**	**5055**	**6837**			
	Accident	**5033**	**6347**	**6821**	**474**	**6.07%**

The result of this test is shown in Table 5.3. The mean through traffic percent reduction resulting from the CMS information on the 18 accident cases was 6.07% and the standard deviation of the difference is 7.72%. The 95% confidence interval for the average difference is 5.39% to 6.75%. Since the confidence interval does not include the value of 0, therefore it rejects the null hypothesis that the downstream through traffic percent reduction during the CMS display is 0. As it was expected, the significance level (p=0.000) is smaller than .05, leading to a rejection of the null hypothesis. Therefore, the results indicated that the downstream through traffic volume reduction during the CMS operation time period was significantly different from 0.

Table 5. 3 One Sample t-Test ($p < .05$) for Downstream Volume Reduction

	Test Value = 0						
	N	Mean	Std. Deviation	95% Confidence Interval of the Difference		t	Sig. (2-tailed)
				Lower Bound	Upper Bound		
% reduction	496	6.07	7.72	5.39	6.75	17.51	0.000

5.3.3 Sensitivity Analysis at Site 1

5.3.3.1 Familiarity and Time Constraint Sensitivity Analysis

Twelve and six accidents occurred during the AM-peak and Non-peak period, respectively. The percent reductions between these two time periods were compared to determine the effect of familiarity and time constraints. As shown in Figure 5.4, the average percent reduction in the AM-peak period is more than five times higher (8.45%) than in the non-peak period (1.47%).

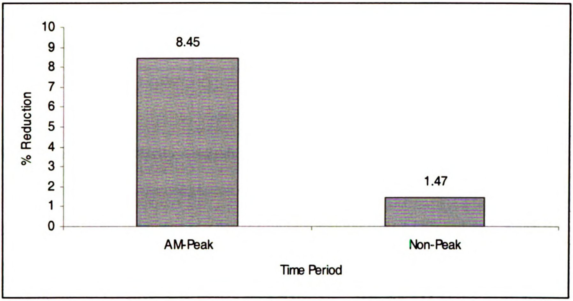


Figure 5. 4 Average Through Traffic Percent Reduction at Site 1

To examine the significance of the mean difference between the two groups, a t-test was conducted. The results are given in Table 5.4. There is a statistically significant difference at the 95% confidence level. This finding is consistent with the literature where drivers stated they would be more willing to divert in the AM-peak period.

Table 5. 4 Independent Sample t-Test for Familiarity and Time Constraint ($p < .05$)

Condition	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
AM-Peak	327	8.45	7.76	0.43	11.94	0.000
Non-Peak	169	1.47	5.16	0.40		

5.3.3.2 Visual Sensitivity Analysis

Depending on the congestion queue distance, the data was classified into two groups: days when the queue reached the diversion point (QD ≥ DP) and days when it did not (QD < DP). There were no accident cases where the congestion queue reached to the diversion point during the non-peak period. Therefore, only the AM-peak period data were classified into these two groups and analyzed.

The results are shown in Table 5.5. The average through traffic reduction when drivers observe the congestion before reaching the diversion point is almost three times higher (13.26%) than where they can not see the congestion (4.55%). The mean difference is statistically significant at the 95% confidence level. The results indicated that when drivers can observe the queue, in addition to seeing the message on the CMS, there is a change in drivers' behavior.

Table 5. 5 Independent Sample t-Test for Visual Sensitivity ($p < .05$)

Condition	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
QD < DP	183	4.66	7.71	0.57	11.90	0.000
QD ≥ DP	144	13.26	4.47	0.37		

QD = queue distance, DP = diversion point

5.3.3.3 Traffic Condition Sensitivity Analysis

As previously noted, downstream I-696 has a 20 - 30 minute period of recurring congestion during the AM-peak period, but downstream I-275 does not experience recurring congestion. To measure the sensitivity of the diversion ratio with and without recurring congestion, the data were separated into the two groups depending on the location of the accident. Since recurring congestion does not exist in the non-peak period only the AM-peak period was compared.

The results are shown in Table 5.6. Almost twice as many drivers diverted to I-275 when an accident occurred on I-696 (11.72%) than diverted to I-696 when an accident occurred on I-275 SB (6.73%). This difference is statistically significant with a 95% confidence interval. Therefore, the results show that the existence of recurring congestion affects the drivers' route diversion behavior.

Table 5. 6 Independent Sample t-Test for Traffic Conditions ($p < .05$)

Route	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
I-696	113	11.72	6.11	0.58	5.80	0.000
I-275	214	6.73	7.99	0.55		

However, in the previous sensitivity analysis, it was determined that drivers are more likely to divert when they can see the congestion queue. Therefore, the AM-peak period accident data was further divided into four groups. Figure 5.5 shows the average through traffic diversion ratio for each group. When the accident occurred on downstream I-696, the diversion ratio was not much different between those who observed the queue (QD ≥ DP, 13.09%) and those who did not (QD < QD, 11.00%). The difference was not statistically significant at a 95% confidence interval ($p = 0.084$, Table 5.7 (a)).

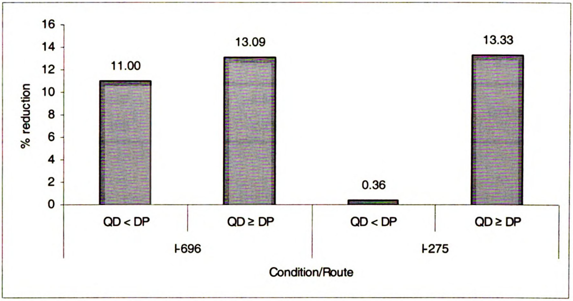


Figure 5.5 Average Percent of Through Traffic Reduction Based on Visual Sensitivity at Site 1

However, when the accident occurred downstream on I-275 SB, the diversion ratio was 13.33% when drivers observed the queue at or before the diversion point, and 0.36% when they did not. This difference is statistically significant with a 95% confidence interval (Table 5.7 (b)).

Table 5. 7 Independent Sample t-Test for Traffic Condition Sensitivity (p < .05)

(a) Accident on I-696

Route	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
QD < DP	74	11.00	6.69	0.78	1.74	0.084
QD ≥ DP	39	13.09	4.60	0.74		

(b) Accident on I-275

Route	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
QD < DP	109	0.36	4.88	0.47	20.32	0.000
QD ≥ DP	105	13.33	4.43	0.43		

One additional analysis of the impact of the presence of downstream congestion was conducted. Table 5.8 shows the test results. When drivers could not observe the queue at the diversion point, the diversion ratio between I-696 and I-275 was statistically different at a 95% confidence interval (p = 0.000) with a greater diversion when the accident occurred on I-696. However, when drivers observed the delayed queue at the diversion point, the diversion ratio was higher for both routes, and the difference between the two routes was not statistically significant with a 95% confidence interval (p = 0.774).

Table 5. 8 Independent Sample t-Test for Route Traffic Condition Sensitivity (p < .05)

(a) When QD < DP

Route	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
I-696	74	11.00	6.69	0.79	12.43	0.000
I-275	109	0.36	4.88	0.47		

(b) When QD ≥ DP

Route	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
I-696	39	13.09	4.60	0.74	0.29	0.774
I-275	105	13.33	4.43	0.43		

From these results, it was determined that at this site, drivers who anticipate recurring congestion on their normal route are more likely to divert to an alternate route when presented with CMS information than drivers who use a route that does not experience recurring congestion. Moreover, drivers who use a route that does not experience recurring congestion are less likely to respond to CMS information unless they observe the congestion queue before reaching the diversion point. This is consistent with the finding that neither route has a significant diversion in the non-peak period, when drivers do not anticipate recurring congestion, nor the congestion queue never reaches the diversion point.

5.4 Analysis of the CMS Effect at Site 2

5.4.1 Description of Site 2

Site 2 is located on M-10 on the border between Oakland County and Wayne County. CMS 2 provides information to eastbound and southbound drivers prior to an interchange which provides drivers with a choice to either stay on southeast bound M-10 or take M-39 southbound and then I-94 eastbound. M-10 provides a slightly shorter route to downtown than does M-39, but the difference is small enough that M-39 is a reasonable alternate route. Both routes have a 55 mph speed limit. The CMS is located on

SB M-10 at Mt. Vernon Road and the upstream ILD (A) is located on M-10 east of Lahser Road. The downstream ILD is located on M-10 south of 8 Mile Road (B) and on M-39 north of 7 Mile Road (C) as shown in Figure 5.6. There is recurring congestion on M-39 during the AM-peak period. The congestion is severe (30 – 50 minutes) and the delay reaches upstream to the M-39/M-10 interchange during a normal AM-peak period. The downstream ILD on M-10 south of 8 Mile Road was not reporting data during this study period.

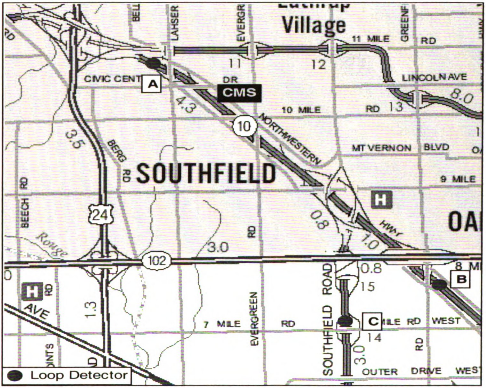


Figure 5.6 Site 2 Location

Due to the malfunctioning of the downstream ILD, traffic data were not available downstream on M-10 EB. Therefore, only data for accidents that occurred downstream on M-39 SB were collected and analyzed to determine the CMS effect at Site 2. Eight accident cases were analyzed at this site. Table 5.9 provides information on each of the accidents. The same analyses as those conducted at site 1 for comparing the upstream volume and downstream volume ratio between accident and the related normal conditions were conducted. The results are shown in the appendix.

Table 5.9 Description of Collected Accident Conditions with CMS Message at Site 2

Case	Accident Date	CMS Operation Time	CMS Accident Message	Congestion Distance	Normal Condition Sample
1	05-21-01	08:29 – 09:29	Accident M-39 SB at 7 Mile Road	Max_QD > DP	38
2	07-10-01	06:56 – 07:56	Accident M-39 SB at Grand River Avenue	Max_QD > DP	38
3	08-29-01	08:38 – 09:38	Accident M-39 SB at Grand River Avenue	Max_QD > DP	38
4	04-10-02	07:56 – 08:56	Accident M-39 SB at Grand River Avenue	Max_QD > DP	38
5	05-09-02	08:03 – 09:03	Accident M-39 SB after Grand River Avenue	Max_QD > DP	38
6	08-02-01	11:46 – 12:46	Accident M-39 SB at Grand River Avenue	Max_QD < DP	35
7	11-13-01	13:07 – 14:07	Accident M-39 SB at Grand River Avenue	Max_QD < DP	35
8	12-10-02	16:11 – 16:11	Accident M-39 SB at 8 Mile Road	Max_QD < DP	35

5.4.2 Diversion Ratio Analysis

Table 5.10 shows the upstream and downstream volume resulting from days with the CMS display and on normal condition days. As can be seen in the table, the through traffic volume reduction ranged from 1.47% to 9.23% when the CMS was displaying an accident message. The average through traffic percent reduction due to the CMS information was 5.93% with 4.55% of standard deviation. The 95% confidence interval for the average difference is 5.41% to 6.75%. The confidence interval does not include the value of 0 so it rejects the null hypothesis. The significance level is smaller than .05 so the reduction is statistically significantly different than "0" at a 95% level of confidence. The statistical test result is shown in Table 5.11.

Table 5. 10 Accident and Related Normal Condition Traffic Volume at Site 2

Case	Condition	Upstream Volume	Downstream Volume	Expected Downstream Volume	Downstream Volume Reduction (Exp-Acc)	% Reduction
Case 1	Normal	4031	4427			
	Accident	3953	4065	4342	277	6.38%
Case 2	Normal	4909	5609			
	Accident	4724	4908	5407	499	9.23%
Case 3	Normal	3871	4259			
	Accident	4183	4471	4604	133	2.89%
Case 4	Normal	4399	4895			
	Accident	4763	4845	5304	459	8.65%
Case 5	Normal	4352	4838			
	Accident	4366	4429	4856	427	8.79%
Case 6	Normal	2440	3627			
	Accident	2543	3601	3785	184	4.86%
Case 7	Normal	2430	3789			
	Accident	2388	3510	3726	216	5.78%
Case 8	Normal	3266	5498			
	Accident	3309	5493	5575	82	1.47%
Average	**Normal**	**3712**	**4618**			
	Accident	**3779**	**4415**	**4700**	**285**	**5.93%**

Table 5. 11 One Sample t-Test ($p < .05$) for Downstream Volume Reduction

	Test Value = 0						
	N	Mean	Std. Deviation	95% Confidence Interval of the Difference		t	Sig. (2-tailed)
				Lower Bound	Upper Bound		
% reduction	295	5.93	4.55	5.41	6.45	22.37	0.000

5.4.3 Sensitivity Analysis at Site 2

Site 2 has recurring congestion on M-39 during the AM-peak period and the congestion backed up through the M-39/M-10 interchange even on normal days. Also, there was a malfunction on the M-10 downstream ILD during the research period so traffic data were not collected downstream on M-10. Therefore, the only sensitivity test that could be conducted at this site was the AM-peak versus the non-peak period difference.

5.4.3.1 Familiarity and Time Constraint Sensitivity Analysis

Five accidents occurred during the AM-peak period and three accidents occurred during the non-peak period. Figure 5.7 shows the average through traffic percent reduction at the downstream location. There is a higher percent reduction in the AM-peak period (7.06%) than in the non-peak period (3.89%).

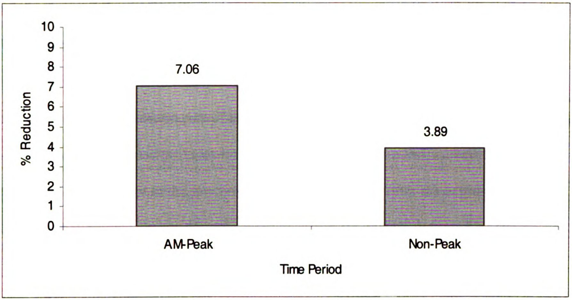


Figure 5.7 Average Through Traffic Percent Reduction at Site 2

From the result of independent sample t-test, the mean difference between these two groups is statistically significant at a 95% confidence level (Table 5.12). This result is consistent with the results from Site 1.

Table 5. 12 Independent Sample t-Test for Familiarity and Time Constraint ($p < .05$)

Condition	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
AM-Peak	190	7.06	4.25	0.31	6.06	0.000
Non-Peak	105	3.89	4.38	0.43		

5.5 Analysis of the CMS Effect at Site 3

5.5.1 Description of Site 3

Site 3 is located on I-96 in Wayne County. I-96 has a 6 mile long express/local configuration in the western part of the Detroit Metropolitan area. A CMS located on EB I-96 at Beech Daly Road provides information on downstream traffic conditions to eastbound drivers prior to the junction where drivers select either the express or the local lanes. Both highways have a 65 mph speed limit and are exactly the same length. However, the drivers on the local lanes can access the surface streets via exit rampa, but the express lanes cannot.

The upstream ILD (A) was located on I-96 approximately one quarter mile west of Outer Drive. Two downstream ILDs located on I-96 east of Evergreen Road collected traffic data at locations situated the same distance from the CMS, after the freeway separates into the express lanes (B) and the local lanes (C). The CMS 27 located on the EB I-96 express lanes at Burt and CMS 28 located on the EB I-96 local lanes at Evergreen provide the same downstream traffic information to drivers in advance of the I-96/M-39 interchange. The location of the upstream ILD on I-96 covers six lanes and both downstream ILDs cover three lanes each. Figure 5.8 shows the location of study Site 3. In a normal AM-peak period, the upstream and the downstream express lanes do not experience recurring congestion but the downstream local lanes have severe recurring congestion.

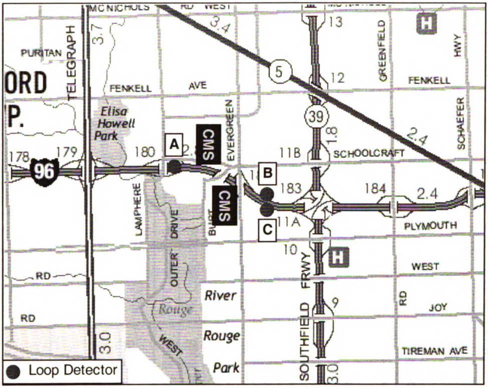


Figure 5.8 Site 3 Location

Data on thirteen accidents were collected at Site 3. Table 5.13 shows the information for each accident and Table 5.14 shows the upstream and downstream volumes for both accident and normal conditions. There was construction during August and September in 2001 and two of the thirteen accidents occurred during this construction period. The related normal conditions for these two accident cases (case 4 and 10) were also collected during the same construction period. The upstream volume and downstream volume ratio between accident and the related normal conditions are also provided in the appendix.

Table 5.13 Description of Collected Accident Conditions with CMS Message at Site 3

Case	Accident Date	CMS Operation Time	CMS Accident Message	Express Lanes Traffic Condition	Local Lanes Traffic Condition	Normal Condition Sample
1	10-16-01	08:22 – 09:22	Accident I-96 EB Express at Wyoming Road	No Congestion	Congested	34
2	02-20-02	08:10 – 09:10	Accident I-96 EB Express at Wyoming Road	No Congestion	Congested	34
3	03-18-02	07:10 – 08:10	Accident I-96 EB Express after Greenfield Road	No Congestion	Congested	34
4	08-06-01	06:28 – 07:28	Accident I-96 EB Local at Wyoming Road	No Congestion	No Congestion	11
5	06-26-02	07:15 – 08:15	Accident I-96 EB Local at Wyoming Road	No Congestion	Congested	34
6	11-08-01	08:17 – 09:17	Accident I-96 EB at Davison Avenue	No Congestion	Congested	34
7	11-13-01	08:28 – 09:28	Accident I-96 EB at Grand Blvd	No Congestion	Congested	34
8	03-28-02	08:13 – 09:13	Accident I-96 EB at Livernois Road	No Congestion	Congested	34
9	04-30-02	07:13 – 08:13	Accident I-96 EB at Grand River Avenue	No Congestion	Congested	34
10	09-10-01	14:39 – 15:39	Accident I-96 EB Express at Schaefer Road	No Congestion	No Congestion	10
11	10-23-01	09:54 – 10:54	Accident I-96 EB Express at Davison Avenue	No Congestion	No Congestion	33
12	10-16-01	12:26 – 13:26	Accident I-96 EB Local at Schaefer Road	No Congestion	No Congestion	33
13	09-10-02	15:19 – 16:19	Accident I-96 EB Local at Wyoming Road	No Congestion	No Congestion	33

Table 5. 14 Accident and Related Normal Condition Traffic Volume at Site 3

Case	Condition	Upstream Volume	Downstream Volume	Expected Downstream Volume	Downstream Volume Reduction (Exp-Acc)	% Reduction
Case 1	Normal	7313	3844			
	Accident	6787	3725	3565	-160	-4.58%
Case 2	Normal	7887	4329			
	Accident	7621	4266	4180	-86	-2.14%
Case 3	Normal	10042	5837			
	Accident	9643	5807	5604	-203	-3.68%
Case 4	Normal	6387	2923			
	Accident	5882	2650	2693	43	1.55%
Case 5	Normal	9977	5809			
	Accident	9645	5303	5615	312	5.51%
Case 6	Normal	7543	4042			
	Accident	7444	3953	3986	33	0.75%
Case 7	Normal	7045	3619			
	Accident	6906	3583	3544	-39	-1.17%
Case 8	Normal	7735	4195			
	Accident	7661	4070	4152	82	1.90%
Case 9	Normal	10013	5831			
	Accident	10202	5817	5940	123	2.02%
Case 10	Normal	5498	2072			
	Accident	5668	1969	2136	167	7.67%
Case 11	Normal	4625	1883			
	Accident	4415	1781	1798	17	0.82%
Case 12	Normal	4850	2916			
	Accident	3969	2329	2387	58	2.25%
Case 13	Normal	6824	4125			
	Accident	6888	4084	4165	81	1.87%
Average	**Normal**	**7365**	**3956**			
	Accident	**7133**	**3795**	**3828**	**33**	**0.54%**

From the table, the through traffic volume reduction ranged from -4.58% to 7.67% during the time the CMS was displaying an accident message.

5.5.2 Diversion Ratio Analysis

From the data provided in Table 5.15, the mean through traffic percent reduction due to the CMS information was 0.54% with 4.04% of standard deviation. The 95% confidence interval for the average difference is 0.14% to 0.94%. The confidence interval does not include the value of 0. The significance level (p=0.008) is smaller than .05 leading to the rejection of the null hypothesis. Therefore, the result indicated that the downstream through traffic volume reduction was significantly different from 0 at a 95% confidence level. However, this diversion was very small compared to the previous two sites.

Table 5. 15 One Sample t-Test (p < .05) for Downstream Volume Reduction

	Test Value = 0						
	N	Mean	Std. Deviation	95% Confidence Interval of the Difference		t	Sig. (2-tailed)
				Lower Bound	Upper Bound		
% reduction	392	0.54	4.04	0.14	0.94	2.65	0.008

Three of the accidents studied occurred in the peak period on the express lanes, and the CMS provided the accident information to the upstream drivers (cases 1, 2 and 3). In these three cases, instead of drivers diverting to the local lanes as might have been expected, more drivers used the express lanes than on normal days. The percent of through traffic on the express lanes increased (case 1 = 4.58%, case 2 = 2.14%, and case 3 = 3.68%) compared with the same time period on normal days. Figure 5.9 provides the downstream speed profiles for one of these accident days (case 3).

As can be seen in Figure 5.9, even though there is an accident on the express lanes, there was no congestion or speed reduction on these lanes. However, even though the accident occurred on the express lanes, congestion on the local lanes started earlier than under normal conditions. The other two accidents cases where the volume increased on the express lanes showed similar traffic speed characteristics.

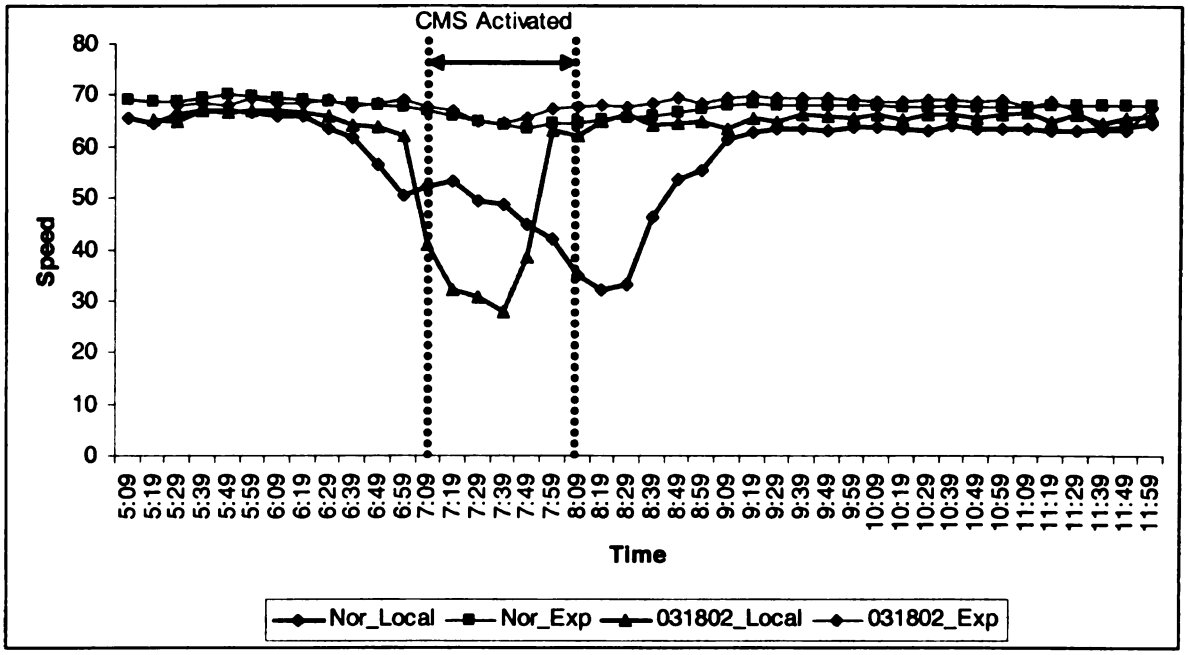


Figure 5. 9 Downstream Speed Profile between Accident and Normal Conditions (Case 3: Accident on I-96 EB Express after Greenfield Road 07:10 – 08:10, 03-18-02)

Based on the results of these three accident cases, it is clear that even though the CMS provides accident information on their preferred route, drivers tend to ignore the CMS information when the alternate route is known to experience recurring congestion, even an normal days.

The mean reduction for accidents occurring on the local lanes in the AM-peak period or on the express lanes in the non-peak period is shown in Table 5.16. In both of these conditions, the alternate path would not be experiencing recurring congestion. The mean through traffic reduction was 1.95% for these 10 accidents. This reduction is statistically significantly different than zero, as shown in Table 5.16.

Table 5. 16 One Sample t-Test (p< .05) for Downstream Volume Reduction without Case 1, 2 and 3

	Test Value = 0						
	N	Mean	Std. Deviation	95% Confidence Interval of the Difference		t	Sig. (2-tailed)
				Lower Bound	Upper Bound		
% reduction	290	1.95	3.40	1.56	2.34	9.78	0.000

5.5.3 Sensitivity Analysis at Site 3

5.5.3.1 Familiarity and Time Constraint Sensitivity Analysis

As was done at the previous sites, the AM-peak period and the non-peak period diversion ratios were compared. Table 5.17 (a) shows that the mean reduction due to the CMS information was - 0.11% for the AM-peak period and 2.23% for the non-peak period. These differences are statistically significant at a 95% confidence level.

However, this result included the three accident cases which occurred on the express lane in the AM peak period (case 1, 2 and 3). Table 5.17 (b) shows the comparison of the diversion ratio without these three cases. The results show that there was more diversion during the non-peak period (2.23%) than during the AM-peak period

(1.78%). However, this difference is not statistically significant at a 95% level of confidence. The diversion ratio sensitivity based on familiarity and time at site 3 was not consistent with the results of the previous two sites. However, this is at least partially explained by the fact that drivers on the local lanes may plan to leave I-96 prior to the point when the local and express lanes merge.

Table 5. 17 Independent Sample t-Test for Familiarity and Time Constraint ($p < .05$)

(a) All Accident Cases

Condition	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
AM-Peak	283	-0.11	4.04	0.24	5.61	0.000
Non-Peak	109	2.23	3.55	0.34		

(b) All Accident Cases exclude case 1, 2, and 3

Condition	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
AM-Peak	181	1.78	3.30	0.25	1.07	0.284
Non-Peak	109	2.23	3.55	0.34		

5.5.3.2 Visual Sensitivity Analysis

Visual sensitivity was not tested at Site 3 because of lack of comparable cases. The local lanes were always congested in the peak period, and never congested in the non-peak period.

5.5.3.3 Traffic Condition Sensitivity Analysis

As mentioned before, the downstream local lanes have recurring congestion during the AM-peak period but the express lanes do not. As expected, the percent reduction on the congested lanes and the non congestion lanes was significantly different at a 95% confidence level as shown in Table 5.18. This is consistent with the finding at site 2.

Table 5. 18 Independent Sample t-Test for Traffic Condition (p < .05).

Condition	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
Express	102	-3.47	2.89	0.29	15.63	0.000
Local	45	4.54	2.78	0.42		

5.6 Analysis of the CMS Effect at Site 4

5.6.1 Description of Site 4

Site 4 is located on M-39 in Wayne County. This is the closest site to the downtown Detroit area. This site does not have an alternate freeway route, therefore drivers can only divert to surface streets via an exit ramp in response to the CMS information. The CMS is located on SB M-39 at Chicago Road and provides information on downstream traffic conditions to southbound drivers. The upstream ILD (A) is located on M-39 north of Wadsworth Road which is 0.3 miles before drivers receive information from the CMS. The downstream ILD (B) is located on M-39 north of Cathedral Road which is 1.2 miles south of the upstream ILD. The upstream ILD is located immediately downstream from the I-96/M-39 interchange. The entering ramp traffic from eastbound I-96 to southbound M-39 at the interchange is merging with the southbound M-39 traffic at this location. This merge results in severe congestion during the AM-peak period, while the downstream location has less congestion. Figure 5.10 shows the geographic location of Site 4.

Figure 5.10 Site 4 Location

Data from eight accident cases were collected and analyzed to determine the effectiveness of the CMS at this site. Table 5.19 provides information on each accident. Table 5.20 shows the upstream and downstream volume under accident conditions and for the same time period under normal conditions. The upstream volume and downstream volume ratio distribution between accident and the related normal conditions are shown in the appendix.

Table 5.19 Description of Collected Accident Conditions with CMS Message at Site 4

Case	Accident Date	CMS Operation Time	CMS Accident Message	Congestion Delay	Normal Condition Sample
1	10-31-01	08:31 – 09:31	Accident M-39 SB after Warren Avenue	Observed	43
2	12-04-01	08:32 – 09:32	Accident M-39 SB after Warren Avenue	Observed	43
3	09-13-01	08:57 – 09:57	Accident M-39 SB at Warren Avenue	Observed	43
4	09-27-01	06:50 – 07:50	Accident M-39 SB at Ford Road	Observed	43
5	03-18-02	06:24 – 07:24	Accident M-39 SB after Warren Avenue	Observed	43
6	05-31-01	09:46 – 10:46	Accident M-39 SB at Warren Avenue	Not observed	42
7	11-26-01	10:21 – 11:21	Accident M-39 SB at Oakwood Blvd	Not observed	42
8	10-03-02	11:25 – 12:25	Accident M-39 SB at Ford Road	Not observed	42

Table 5. 20 Accident and Related Normal Condition Traffic Volume at Site 4

Case	Condition	Upstream Volume	Downstream Volume	Expected Downstream Volume	Downstream Volume Reduction (Exp-Acc)	% Reduction
Case 1	Normal	3784	5979			
	Accident	3695	5808	5842	34	0.44%
Case 2	Normal	3805	5943			
	Accident	3978	6196	6215	19	0.17%
Case 3	Normal	3233	5268			
	Accident	3282	5115	5350	235	4.26%
Case 4	Normal	4750	7371			
	Accident	4708	6872	7315	443	5.86%
Case 5	Normal	4243	6947			
	Accident	3854	5941	6319	378	5.79%
Case 6	Normal	2700	4369			
	Accident	2696	4229	4364	135	3.02%
Case 7	Normal	2537	4341			
	Accident	2366	3938	4051	113	2.65%
Case 8	Normal	2588	4602			
	Accident	2711	4840	4825	-15	-0.54
Average	**Normal**	**3455**	**5603**			
	Accident	**3411**	**5367**	**5535**	**168**	**3.03%**

5.6.2 Diversion Ratio Analysis

When the CMS provided accident information, an average of 2.72% of the drivers changed their route at Site 4. This diversion ratio is statistically different from "0" within a 95% confidence interval. Table 5.21 shows the test results.

Table 5. 21 One Sample t-Test (p < .05) for Downstream Volume Reduction

	Test Value = 0						
	N	Mean	Std. Deviation	95% Confidence Interval of the Difference		t	Sig. (2-tailed)
				Lower Bound	Upper Bound		
% reduction	341	2.72	4.60	2.23	3.21	10.90	0.000

5.6.3 Sensitivity Analysis at Site 4

5.6.3.1 Familiarity and Time Constraint Sensitivity Analysis

As before, the data was classified into two groups to determine the familiarity and time constraint sensitivity. Using the data in Table 5.22, the average through traffic reduction in the AM-peak period is almost two times higher (3.31%) than in the non-peak period (1.71%) at this site. The mean reduction is statistically significantly different with a 95% confidence interval. This sensitivity result is consistent with the results at Site1 and Site 2.

Table 5. 22 Independent Sample t-Test for Familiarity and Time Constraint (p < .05)

Condition	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
AM-Peak	215	3.31	4.73	0.32	3.13	0.002
Non-Peak	126	1.71	4.21	0.37		

The upstream location on this site has severe recurring congestion during the normal AM-peak period. Therefore, the drivers can always observe the congested delay at the upstream location.

5.7 Analysis of the CMS Effect at Site 5

5.7.1 Description of Site 5

Site 5 is located on I-94 in Wayne County. This site also does not have a freeway alternate route. The CMS is located on I-94 at 10 Mile Road and provides information on the downstream traffic condition to the southwest bound drivers. The upstream ILD (A) is located north of 10 Mile Road and the downstream ILD (B) is located south of 8 Mile Road. The distance between the upstream and downstream ILD is approximately 2.1 mile. There are surface street exits at 10 Mile, 9 Mile and 8 Mile Roads. Figure 5.11 shows the location of Site 5.There is no recurring congestion at the upstream or downstream ILD locations during the AM-peak period.

Highway construction was conducted during September, October, and November 2002. The construction was conducted with one driving lane closed at the downstream location and this lane closure induced recurring congestion at the downstream location during the AM-peak period, which was not present during the non-construction time period. Therefore, traffic data were not collected and analyzed during this time period.

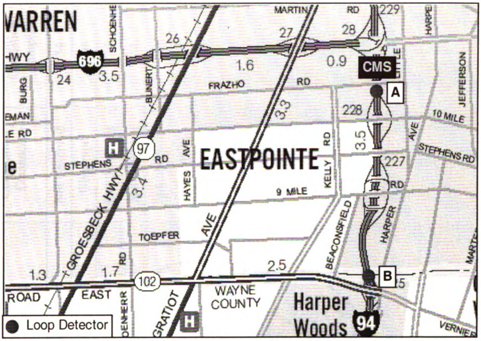


Figure 5.11 Site 5 Location

Thirteen accident conditions were collected and analyzed at site 5. Table 5.23 provides information on the traffic conditions for each accident, and Table 5.24 shows the upstream and downstream volumes on accident days and normal condition days. The upstream volume and downstream volume ratio distribution between accident and the related normal conditions are shown in the appendix.

Table 5.23 Description of Collected Accident Conditions with CMS Message at Site 5

Case	Accident Date	CMS Operation Time	CMS Accident Message	Congestion Distance	Normal Condition Sample
1	07-12-01	06:46 – 07:46	Accident I-94 WB at Chalmers Avenue	Not observed	34
2	08-28-01	07:42 – 08:42	Accident I-94 WB at Chalmers Avenue	Observed	34
3	03-13-02	09:06 – 10:06	Accident I-94 WB at Moross Road	Not observed	34
4	03-28-02	08:55 – 09:55	Accident I-94 WB at Cadieux Avenue	Not observed	34
5	04-08-02	06:21 – 07:21	Accident I-94 WB at Chalmers Avenue	Not observed	34
6	05-06-02	06:31 – 07:31	Accident I-94 WB at Conner Avenue	Observed	34
7	08-06-01	15:33 – 16:33	Accident I-94 WB at Chalmers Avenue	Not observed	24
8	08-08-01	14:03 – 15:03	Accident I-94 WB at Van Dyke Avenue	Not observed	24
9	10-18-01	15:29 – 16:29	Accident I-94 WB at Conner Avenue	Not observed	24
10	11-05-01	15:25 – 16:25	Accident I-94 WB at Chalmers Avenue	Not observed	24
11	11-19-01	14:31 – 15:31	Accident I-94 WB at Conner Avenue	Not observed	24
12	01-09-02	13:26 – 14:26	Accident I-94 WB at MT. Ellitt Avenue	Not observed	24
13	04-17-02	13:29 – 14:29	Accident I-94 WB at Conner Avenue	Not observed	24

Table 5. 24 Accident and Related Normal Condition Traffic Volume at Site 5

Case	Condition	Upstream Volume	Downstream Volume	Expected Downstream Volume	Downstream Volume Reduction (Exp-Acc)	% Reduction
Case 1	Normal	5431	4924			
	Accident	5153	4721	4680	-40	-1.08%
Case 2	Normal	5223	4282			
	Accident	5602	4636	4594	-42	-1.00%
Case 3	Normal	3550	2882			
	Accident	3562	2849	2892	43	1.42%
Case 4	Normal	3742	3028			
	Accident	3877	3189	3138	-51	-1.68%
Case 5	Normal	5015	4933			
	Accident	4524	4328	4451	123	2.71%
Case 6	Normal	5181	4954			
	Accident	4937	4515	4723	208	4.31%
Case 7	Normal	4638	3180			
	Accident	4269	2931	2928	-3	-0.18%
Case 8	Normal	4320	3254			
	Accident	4450	3333	3355	22	0.58%
Case 9	Normal	4642	3190			
	Accident	4815	3280	3311	31	0.85%
Case 10	Normal	4641	3213			
	Accident	4681	3214	3242	28	0.80%
Case 11	Normal	4540	3328			
	Accident	4700	3406	3449	43	1.18%
Case 12	Normal	3859	2985			
	Accident	3863	3015	2988	-27	-0.94%
Case 13	Normal	3891	3010			
	Accident	3736	2936	2890	-26	-1.63%
Average	**Normal**	**4513**	**3628**			
	Accident	**4475**	**3566**	**3588**	**24**	**0.47%**

5.7.2 Diversion Ratio Analysis

An average 0.47% of the through traffic was diverted when the accident message was presented on the CMS (Table 5.25). On average only twenty five vehicles diverted to exit ramps due to the message display. The mean difference is statistically significantly different from 0 at the 95% confidence level.

Table 5. 25 One Sample t-Test (p < .05) for Downstream Volume Reduction

	Test Value = 0						
	N	Mean	Std. Deviation	95% Confidence Interval of the Difference		t	Sig. (2-tailed)
				Lower Bound	Upper Bound		
% reduction	372	0.47	3.35	0.13	0.81	2.70	0.007

5.7.3 Sensitivity Analysis at Site 5

5.7.3.1 Familiarity and Time Constraint Sensitivity Analysis

The data were classified into two groups and the familiarity and time constraint sensitivity test was conducted. The AM-peak period (0.78%) had more diversion than the non-peak period (0.09%) when the CMS message was displayed. However, the difference in the mean diversion ratio is not statistically significantly different at a 95% confidence level. The results of this test are given in Table 5.26.

Table 5. 26 Independent Sample t-Test for Familiarity and Time Constraint (p < .05)

Condition	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
AM-Peak	204	0.78	3.77	0.26	1.97	0.05
Non-Peak	168	0.09	2.73	0.21		

5.7.3.2 Visual Sensitivity Analysis

The sensitivity of diversion to the drivers' ability to see the back of the congestion queue was also tested at Site 5. For this sensitivity analysis, the data were classified into two groups: congestion observed and congestion not observed. Among the thirteen accident cases, two accidents had congestion where drivers encountered the traffic congestion before passing the last downstream exit ramp before the downstream ILD. Therefore, the downstream ratios for these two accident conditions were compared with the others. These accidents occurred during the AM-peak period, therefore, only the AM-peak period accidents when no congestion was observable were used as a comparison group. The results are shown in Table 5.27.

The result is consistent with the previous results. A greater route diversion was found when drivers observed traffic congestion and the difference is a statistically significant at the 95% confidence level.

Table 5. 27 Independent Sample t-Test for Visual Sensitivity ($p < .05$)

Condition	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
Not Observed	136	0.34	3.55	0.30	2.37	0.019
Observed	68	1.65	4.05	0.49		

5.8 Geographic Location Sensitivity Analysis

Figure 5.12 shows the through traffic percent reduction resulting from the CMS display compared with same time period on normal days. As noted in the site descriptions, Site 1 and Site 2 have freeway alternate routes, while Site 4 and Site 5 do not. When drivers are notified of downstream congestion, the through traffic reduction ratio at Site 1 and Site 2 were 6.07% and 5.93% respectively compared to Site 4 and Site 5 reductions of 2.72% and 0.47% respectively. Site 3 was not included in this sensitivity analysis based on the fact that the diversion was to a route where recurring congestion is a daily occurrence.

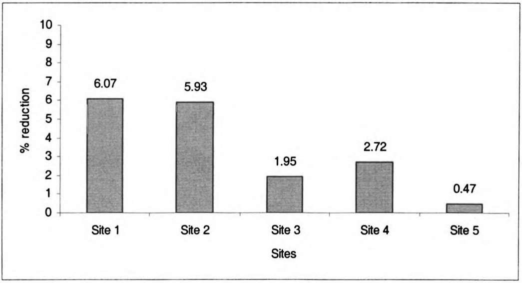


Figure 5.12 Average Through Traffic Percent Reduction Based on Geographic Locations

To examine the significance of the mean reduction in the through traffic volume between a group with an alternate route and a group without an alternate route, a t-Test was conducted. The results are given in Table 5.28. The table shows that the mean reduction due to CMS information was 6.02% for the drivers who have an alternate freeway route and 1.54% for drivers with only surface street alternate routes. These differences are statistically significant at a 95% confidence level.

Table 5. 28 Independent Sample t-Test for Geographic Location ($p < .05$)

Condition	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
With Alt	791	6.02	6.72	0.24	15.71	0.000
Without Alt	713	1.54	4.15	0.16		

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study was conducted to determine the effect of various parameters on the diversion potential of CMS in southeast Michigan by analyzing traffic flow data obtained when a message was displayed. This study used data from five CMS locations on the Detroit freeway system which have different geographic and traffic conditions. The measure of effectiveness (MOE) used to quantify the CMS effect is the percentage of drivers that diverted to an alternate route when they observed a message that an accident had occurred downstream on their current route.

The percentage of vehicles that passed a detector downstream from a diversion opportunity after having encountered a message was compared to this same ratio on days when no message was displayed. The difference between the number of vehicles passing the downstream detector and the number that would have passed this detector under normal conditions was deemed to be the effect of the CMS information. This difference in the ratio of downstream volume to upstream volume was tested for statistical significance.

From the statistical analysis of 60 different accident cases at five different locations, this study determined the characteristics under which a CMS is effective in inducing drivers to change their travel route to avoid a downstream accident. The average percent diversion when a CMS displays a message was 3.43%. However, the diversion ratio is not equal at all CMS sites, or at different times at any given CMS site. The average diversion ratio ranged from a low 0.47% to a high of 6.07% across the five sites, and from a low of -1.96% to a high of 16.44% at different times at a single site. To better understand this variation in the diversion potential, four different factors were considered: time of day; a driver's ability to see the queue resulting from the accident; historical traffic conditions on the alternate route; and geographic location.

For the sensitivity analysis based on the time of day, two different groups; the AM-peak period (06:00 – 09:00) and a non-peak period (10:00 – 16:00) were compared. The AM-peak period traffic has a high percentage of commuters, who are both familiar with the alternate routes to their destination and under some pressure to reach their destination on time. The non-peak period has a higher percentage of drivers that use this route less frequently than commuters, and do not have the obligation to arrive at work at a prescribed time.

From the analysis results, it was determined that drivers during the AM-peak period are more responsive to CMS information than non-peak period drivers. The average diversion ratio during the AM-peak period is as much as five times greater than the Non-peak period (1.47% to 8.45%) at Site 1. Similar differences were also found at the other sites.

To determine the sensitivity of the route diversion to conditions observed by the drivers, a calculation of the congestion distance for each accident case was conducted, and the crash events were categorized into two groups. The first was an accident condition where drivers encountered the congestion upstream from the diversion point, and the second was an accident condition where drivers could not observe the congestion prior to the diversion point. From this analysis, it was shown that the visual observation of congestion impacts the drivers' route diversion behavior. When drivers observe the congestion before reaching the diversion point, the diversion ratio is almost three times higher at Site 1 (4.66% and 13.26%) and over four times higher at Site 5 (0.34% and 1.65%) than when the congestion can not be observed. The difference is statistically significant at the 95% confidence level.

The willingness to divert to an alternate route is sensitive to the drivers' perception of the likelihood of encountering recurring congestion on each route. At site 1, where recurring congestion occurs on I-696 EB but not on I-275 SB, almost twice as many drivers diverted when an accident occurred on I-696 EB (11.72%) than when the accident occurred on I-275 SB (6.73%) during the AM-peak period. In fact, the expectation of congestion has almost as much of an effect on diversion behavior as encountering the congestion. When the accident occurred on the route with recurring congestion (I-696) the diversion ratio is not much different between observing the queue (13.09%) and not observing the queue (11.00%). However, when the accident occurred on the route without recurring congestion (I-275), the diversion ratio was 13.33% when the queue is observed prior to the diversion point, and only 0.36% when it is not observed. This same phenomenon was observed at Sites 4 and 5. Site 4, which has recurring congestion, had a greater diversion (3.31%) than Site 5 (0.78%), which has no recurring congestion during the AM-peak period.

These results led to the conclusion that drivers who anticipate recurring congestion on their normal route are more likely to divert to an alternate route when presented with CMS information than drivers who use a route that does not experience recurring congestion. Drivers who use a route that does not experience recurring congestion are less likely to respond to CMS information unless they observe the congestion queue. This factor may also partially explain the difference between the AM-peak period and the non-peak period diversion ratio, because during the non-peak period drivers would not anticipate recurring congestion on any of the alternate routes.

The final sensitivity analysis was based on the sites geographic location. A comparison was made between sites with and without a freeway alternate route. The average diversion ratio in Site 1 and Site 2, where there is an alternate freeway, were 6.07% and 5.93% respectively compared to Site 4 and Site 5 (where the alternate routes are arterials) reductions of 2.72% and 0.47% respectively. The route diversion ratios due to CMS information were almost four times higher at sites with a freeway alternate route (6.02%) than a site with no alternate route (1.54%). The difference is statistically significant at a 95% confidence level.

6.2 Recommendation

While the percentage of drivers diverting to an alternate route is relatively low, the number of vehicles diverted can be fairly large: At Site 1, when an accident occurs on I-696 in the AM-peak period, between 283 and 1382 vehicles diverted to I-275 as a result of the CMS message. The result of this diversion reduces the network delay and improves safety and the environmental impact of an accident in two ways. First, the diverted vehicles avoid the congestions resulting from the accident, and second, the time in queue for those vehicles that chose to remain on their primary route is reduced. These benefits of a CMS system, however, are not generated equally at all locations on a freeway. The diversion ratio is significantly different based on the existing traffic condition, the geographic location and the drivers' perception of the primary and alternate routes.

NCHRP Synthesis 237 published in 1997 includes a summary of State guidelines for CMS. These guidelines include visibility and readability distances, lateral and vertical placement, placement relative to the closest interchange and the message design. This report concludes that research is necessary to gain a better understanding of CMS potential includes:

"Additional field studies to evaluate message effectiveness in term of motorist response would be useful. The number of documented studies that measured motorist response to CMS messages in real-world operational settings is extremely small and most were conducted in the mid 1970s."

The existing guidelines for the placement of CMS are based on visibility and the time to understand the messages displayed. However, they do not consider the cost effectiveness of CMS. The capital cost (without installation) for a full matrix, LED, 3-line walk-in freeway CMS is $48,000 – $120,000, and the operating cost is $2,400 – $6,000 per year (http://www.benefitcost.its.dot.gov). Therefore, identifying the parameters which influences diversion, and thus the fuel and travel time savings, is important to establish the optimum deployment of a CMS system.

This analysis, based on field observation of drivers' behavior, has contributed to the identification of factors to be considered in determining the potential cost effectiveness of prospective CMS locations.

APPENDIX

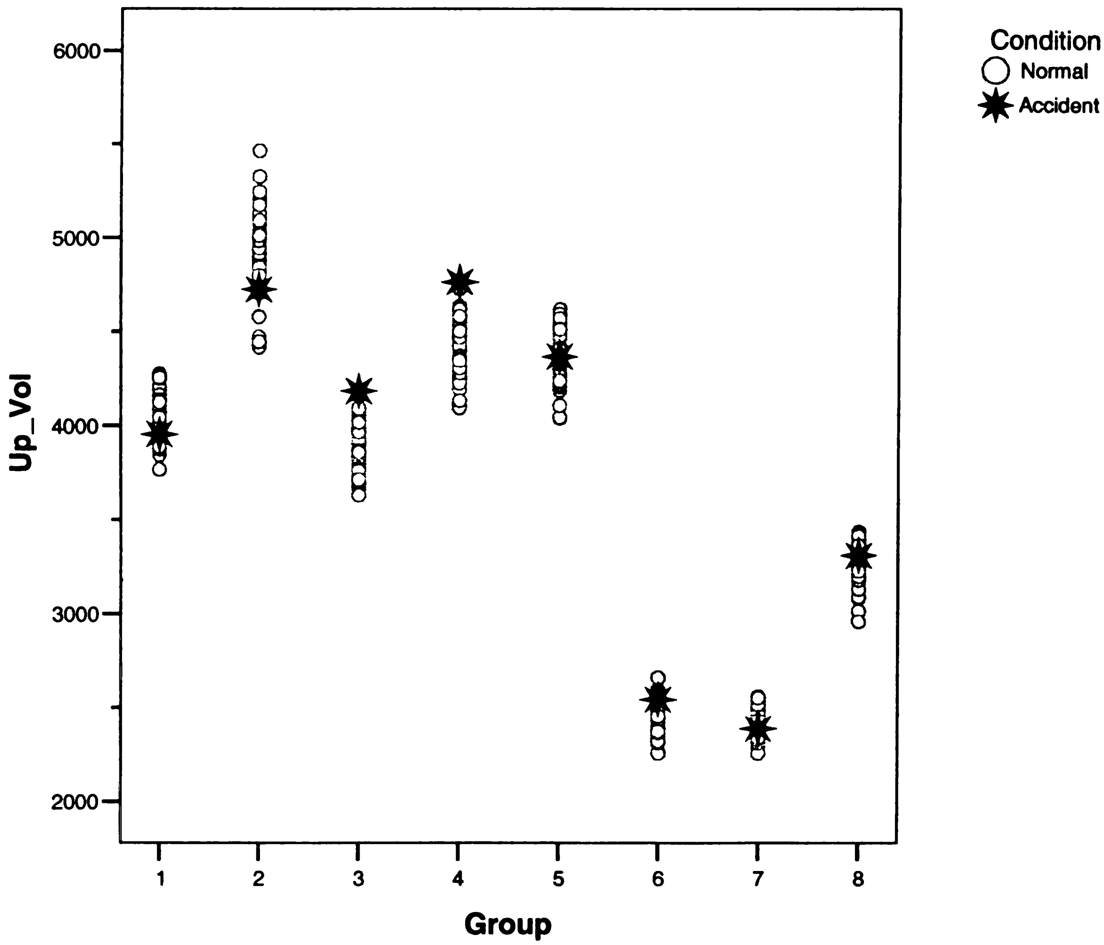


Figure A. 1 Upstream Volume Distribution at Site 2

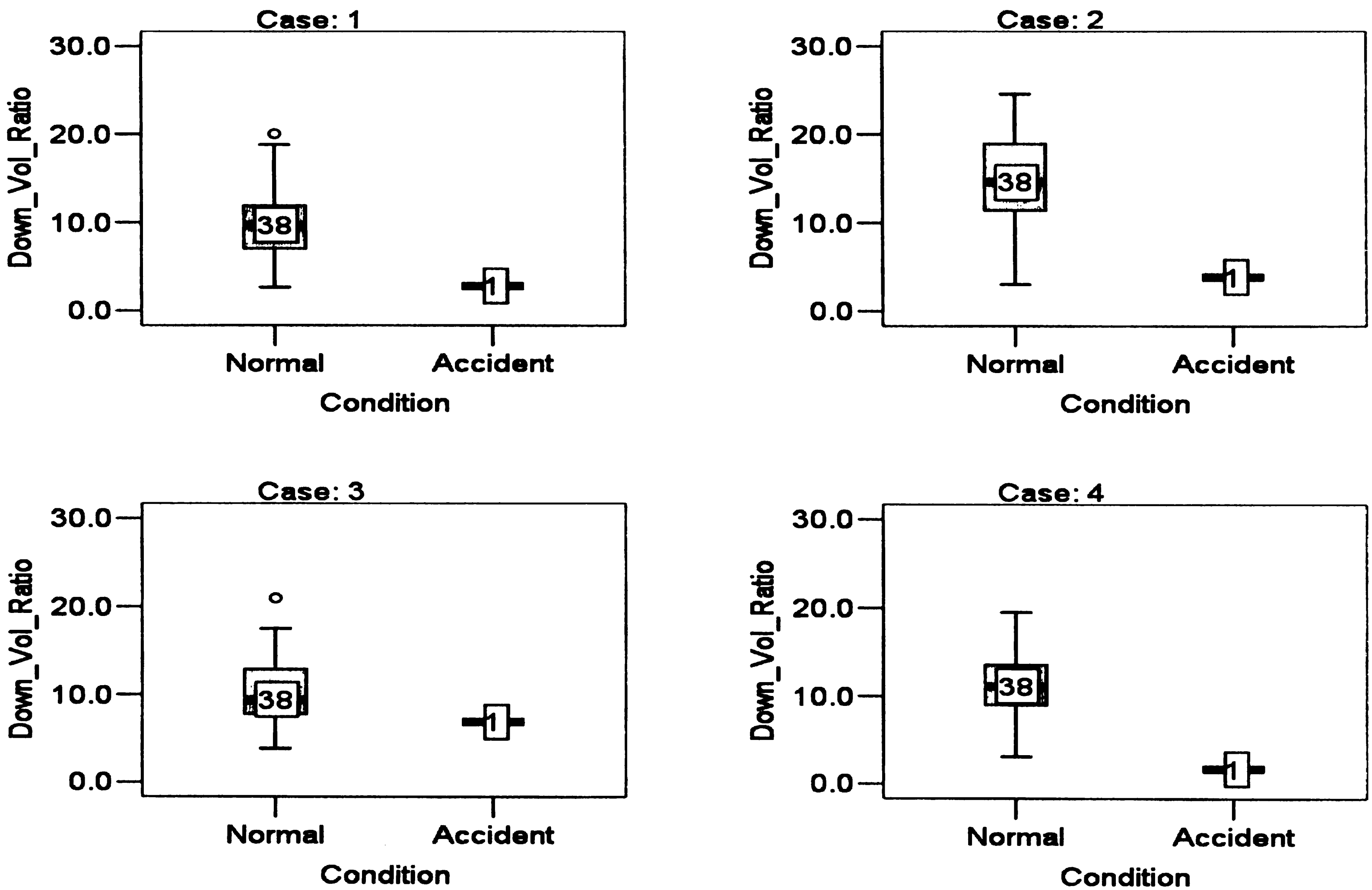


Figure A.2 Downstream Volume Ratio Comparisons at Site 2

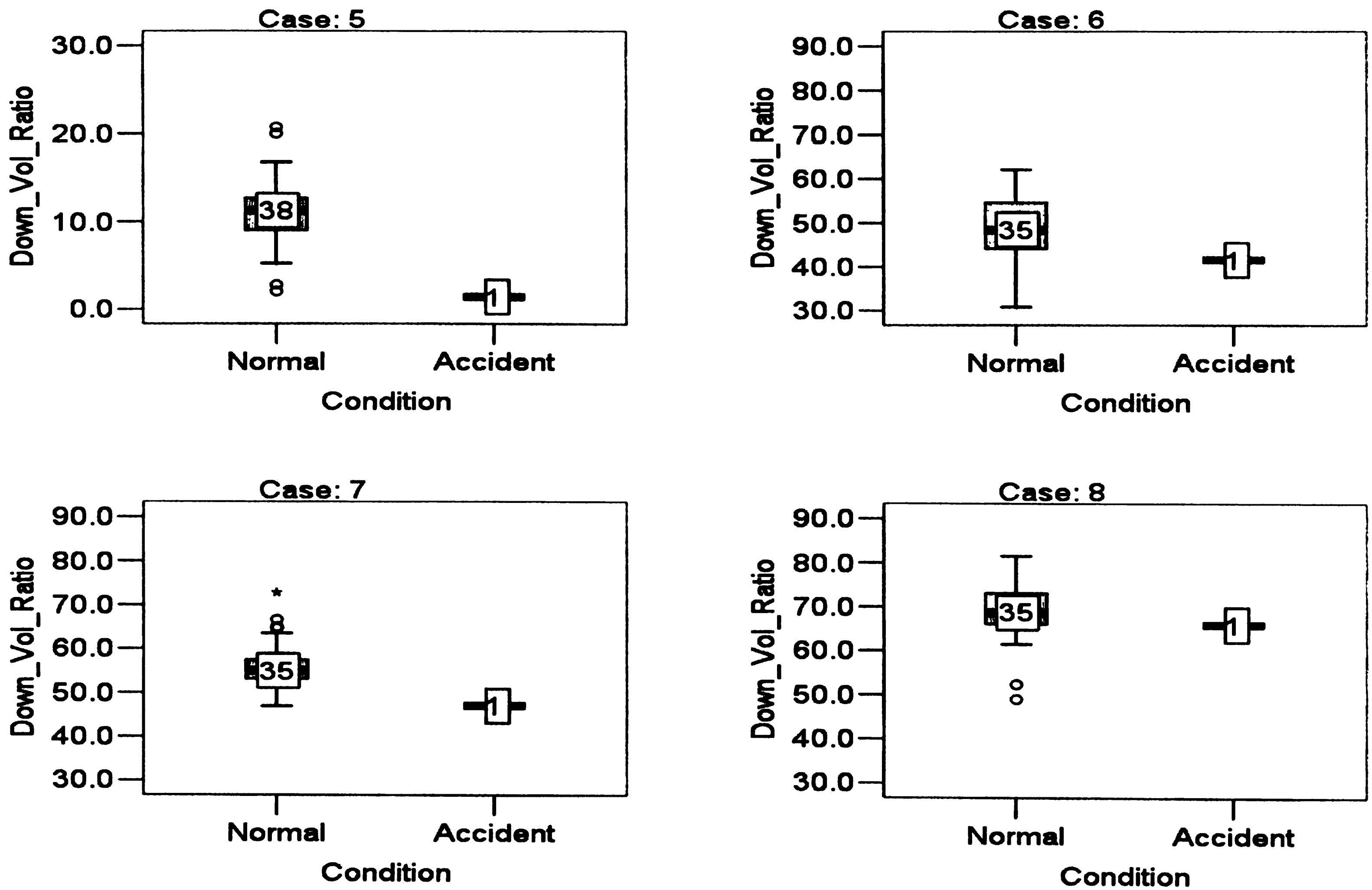


Figure A.2 Downstream Volume Ratio Comparisons at Site 2 (Continued)

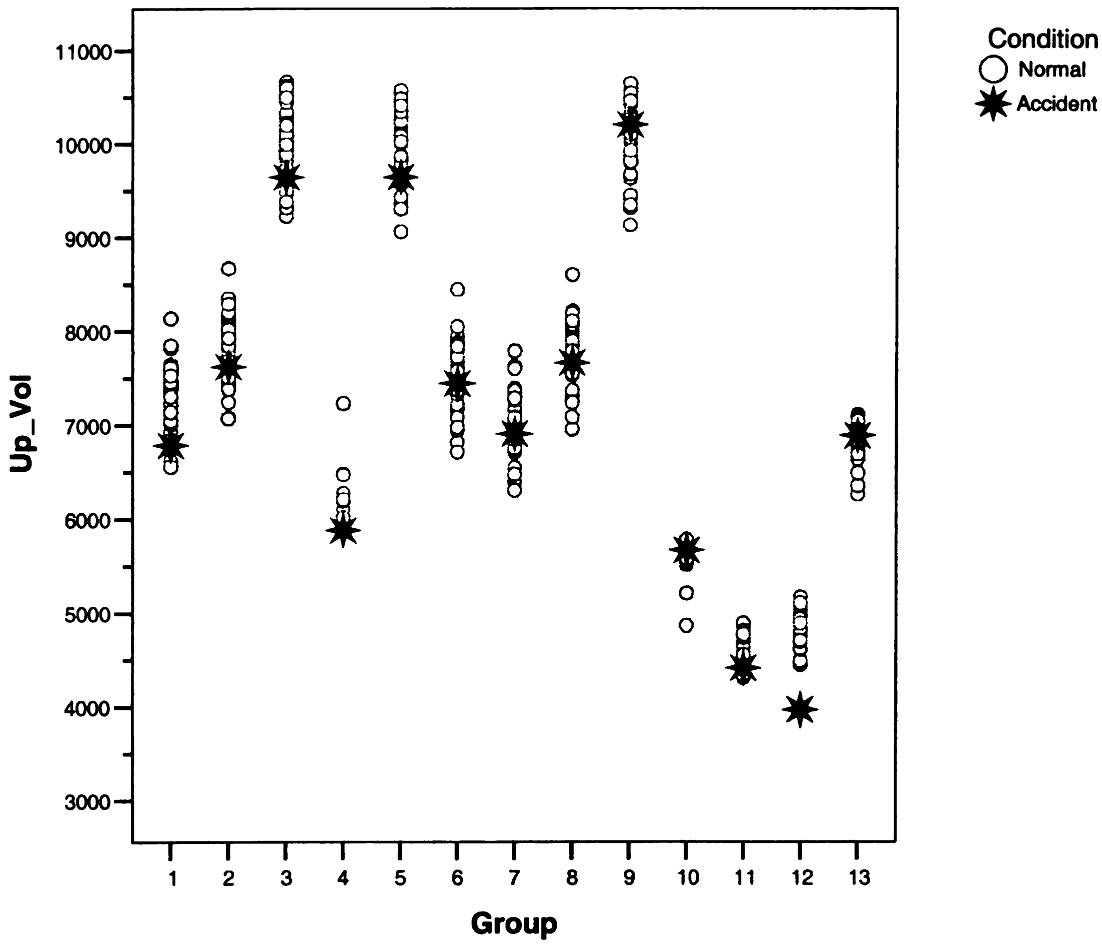


Figure A. 3 Upstream Volume Distribution at Site 3

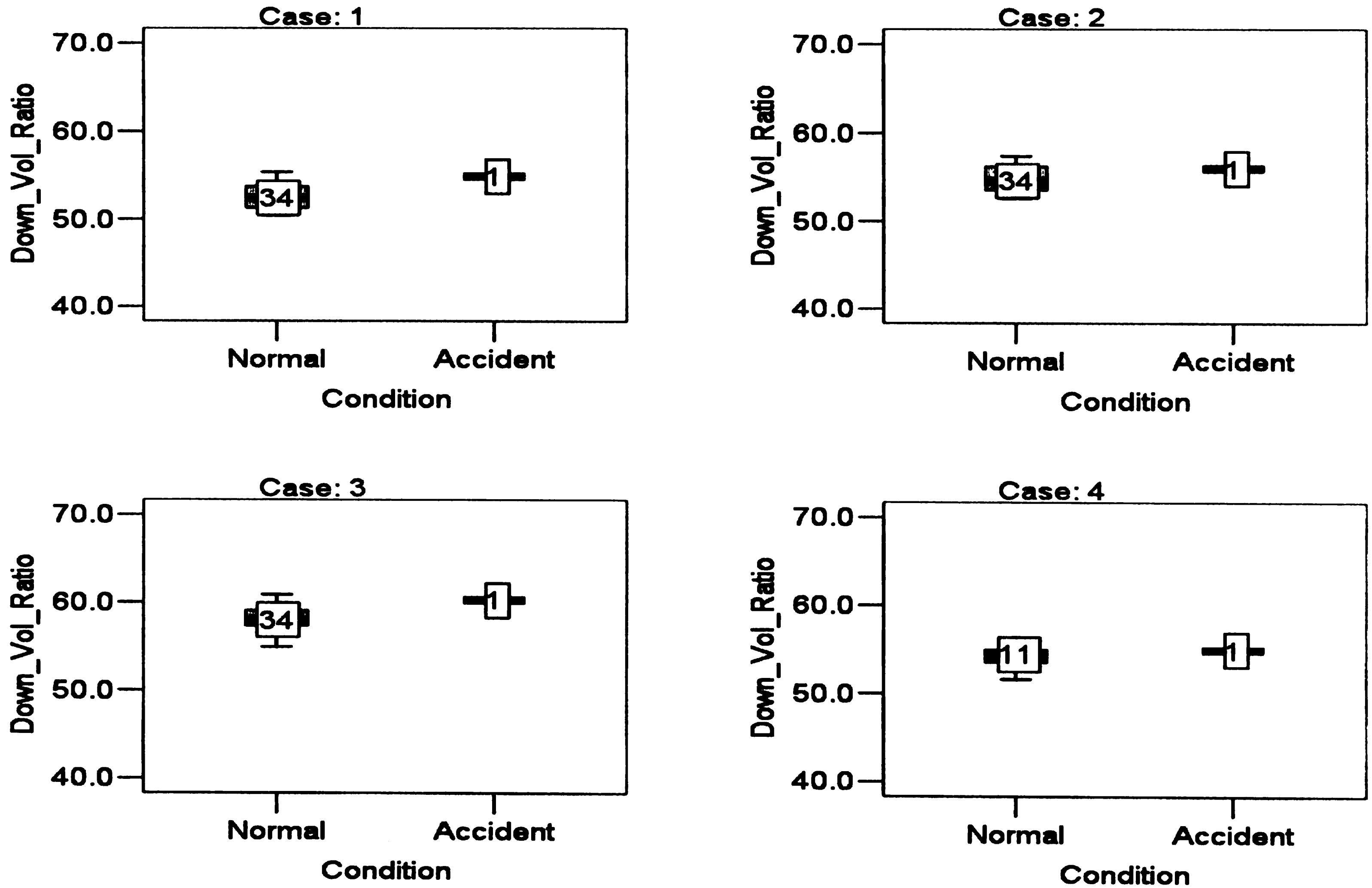


Figure A.4 Downstream Volume Ratio Comparisons at Site 3

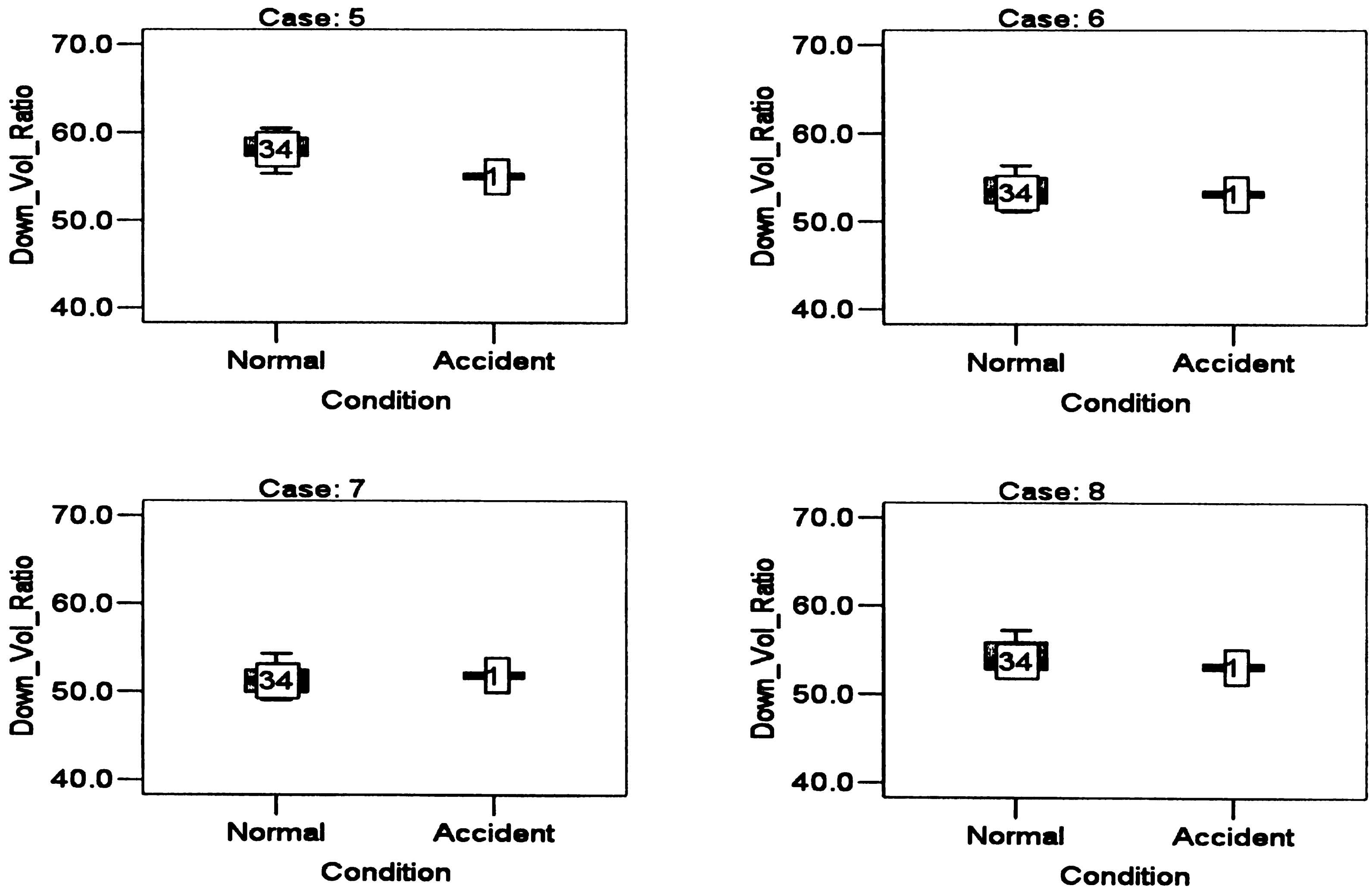


Figure A.4 Downstream Volume Ratio Comparisons at Site 3 (Continued)

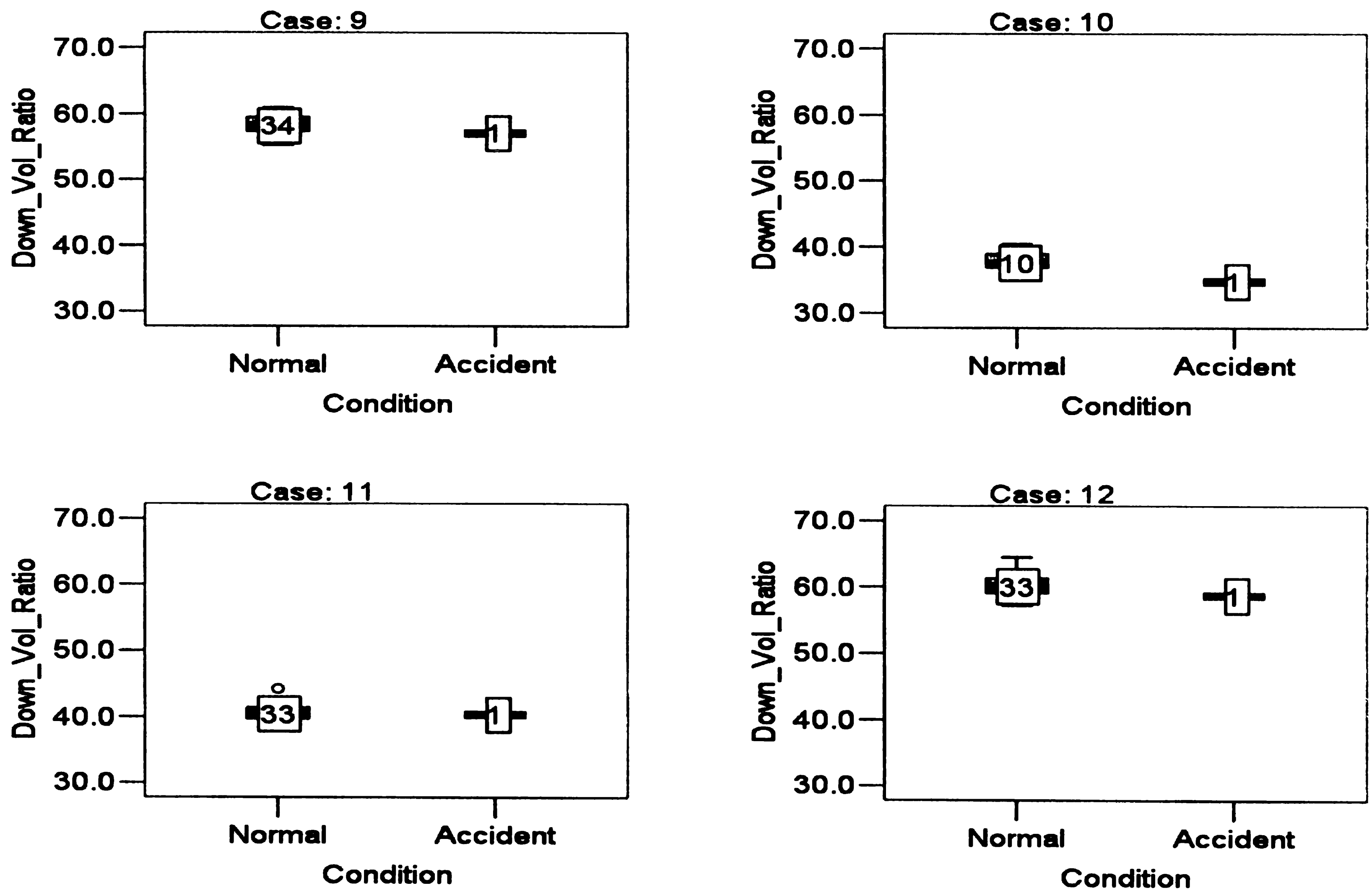


Figure A.4 Downstream Volume Ratio Comparisons at Site 3 (Continued)

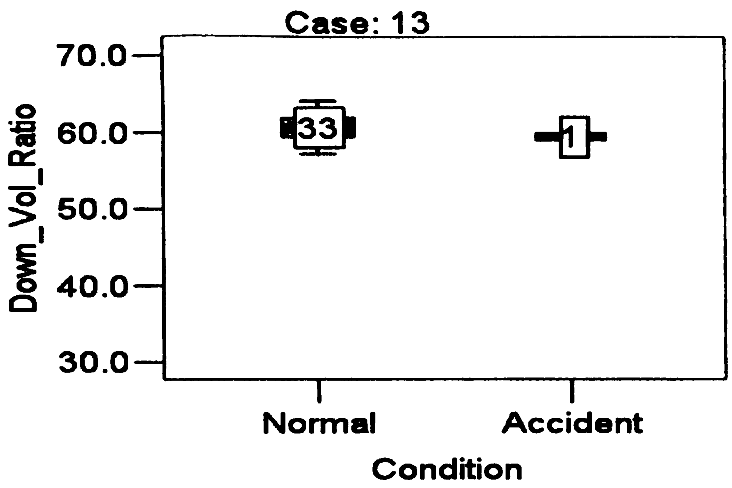


Figure A.4 Downstream Volume Ratio Comparisons at Site 3 (Continued)

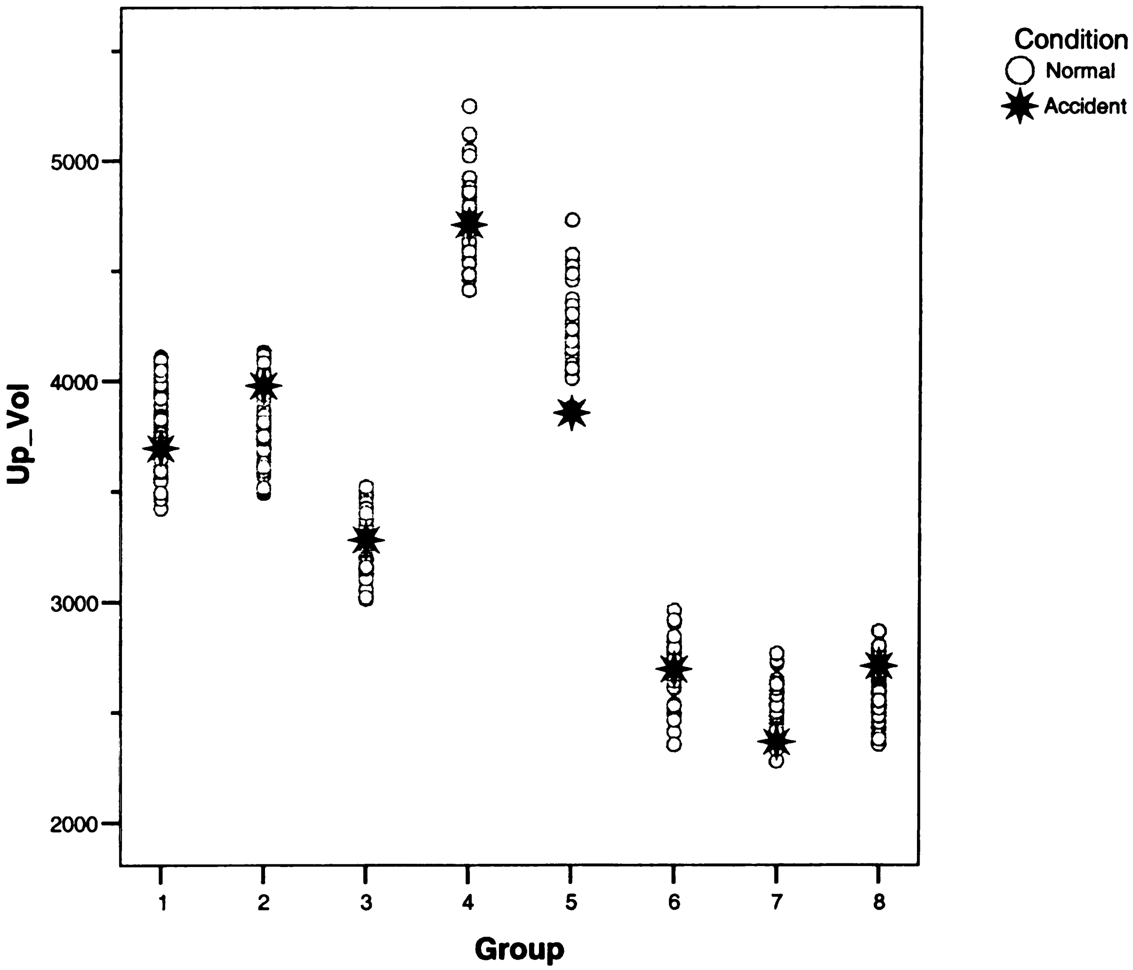


Figure A. 5 Upstream Volume Distribution at Site 4

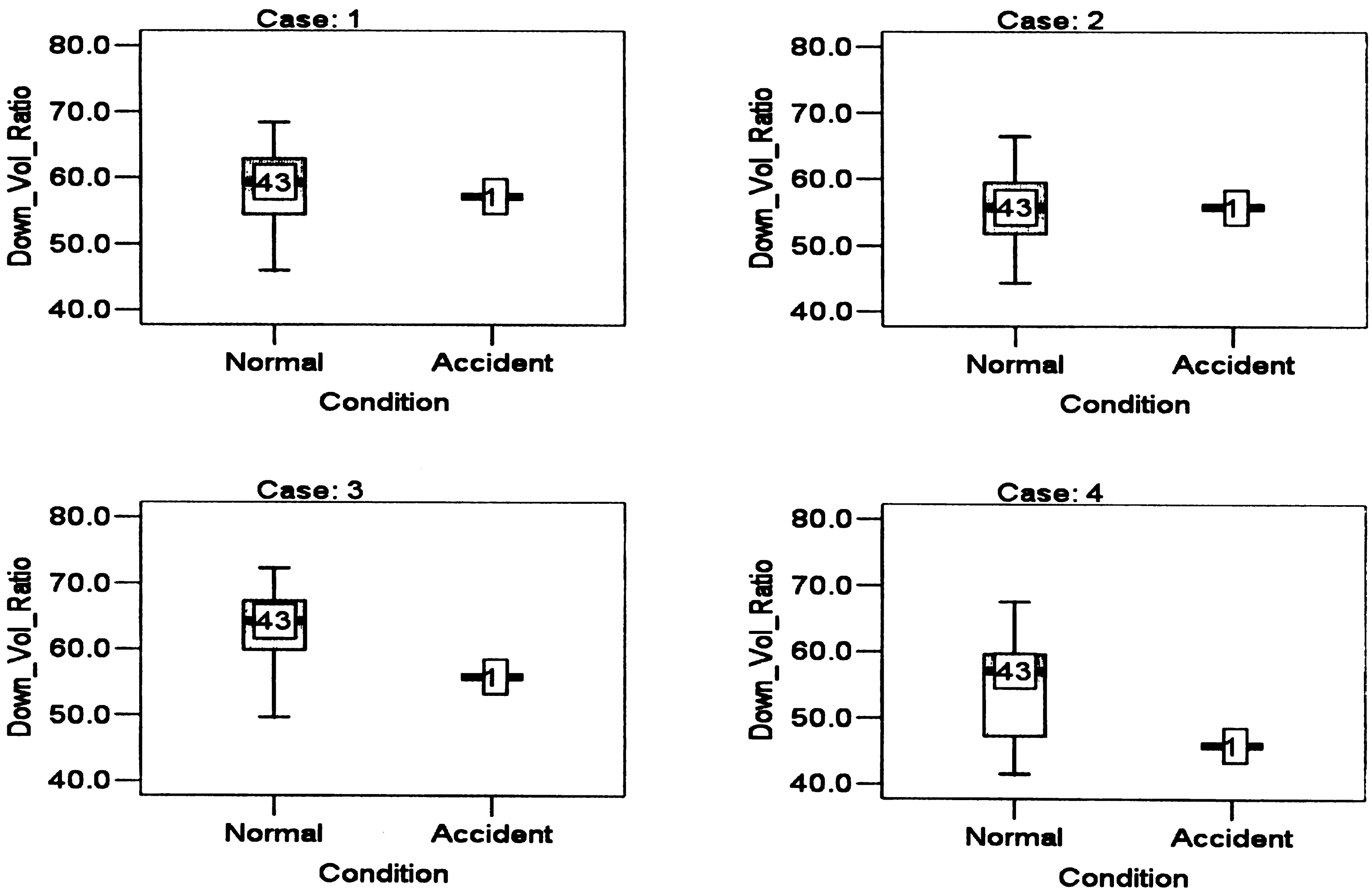


Figure A.6 Downstream Volume Ratio Comparisons at Site 4

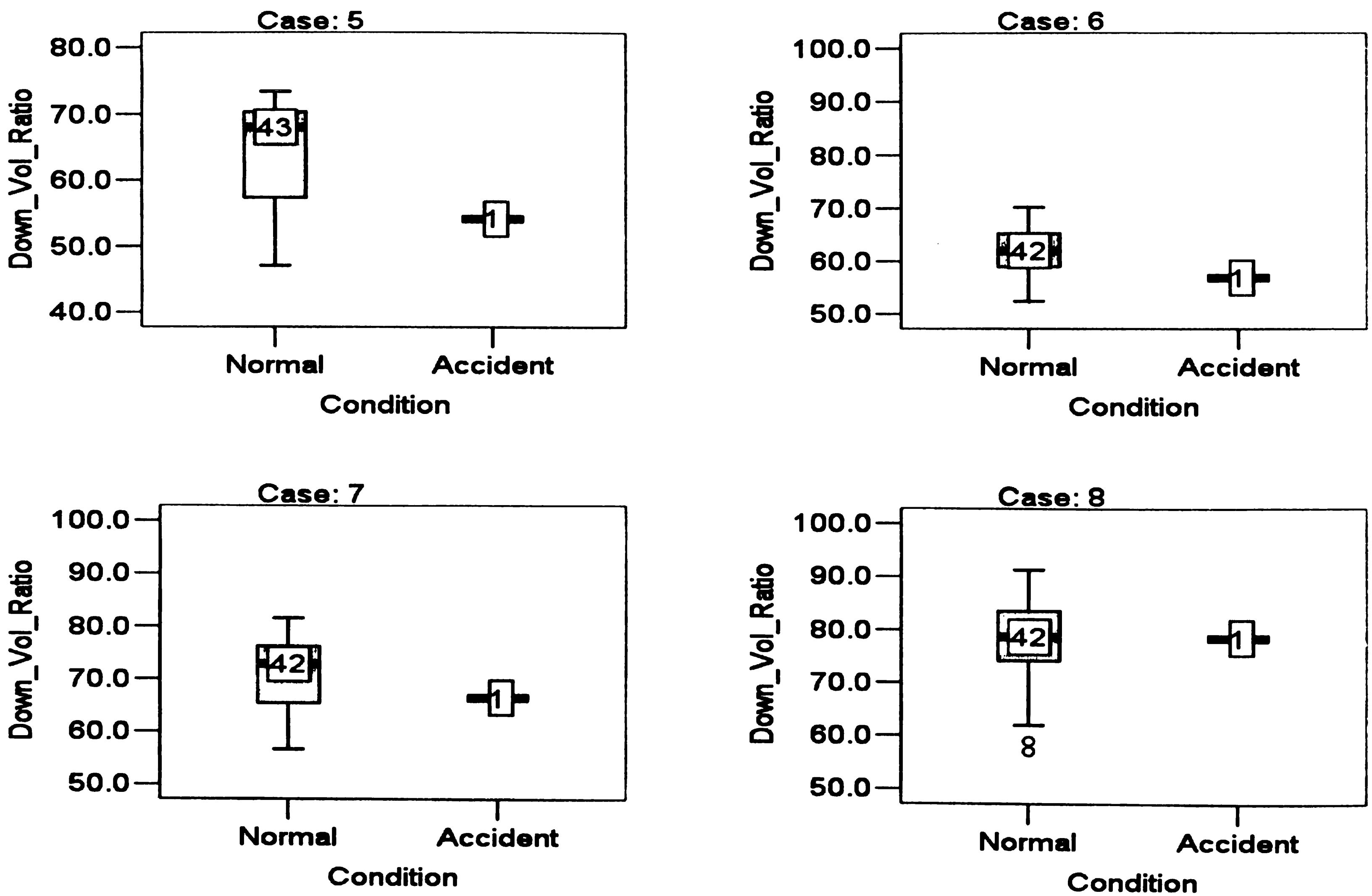


Figure A.6 Downstream Volume Ratio Comparisons at Site 4 (Continued)

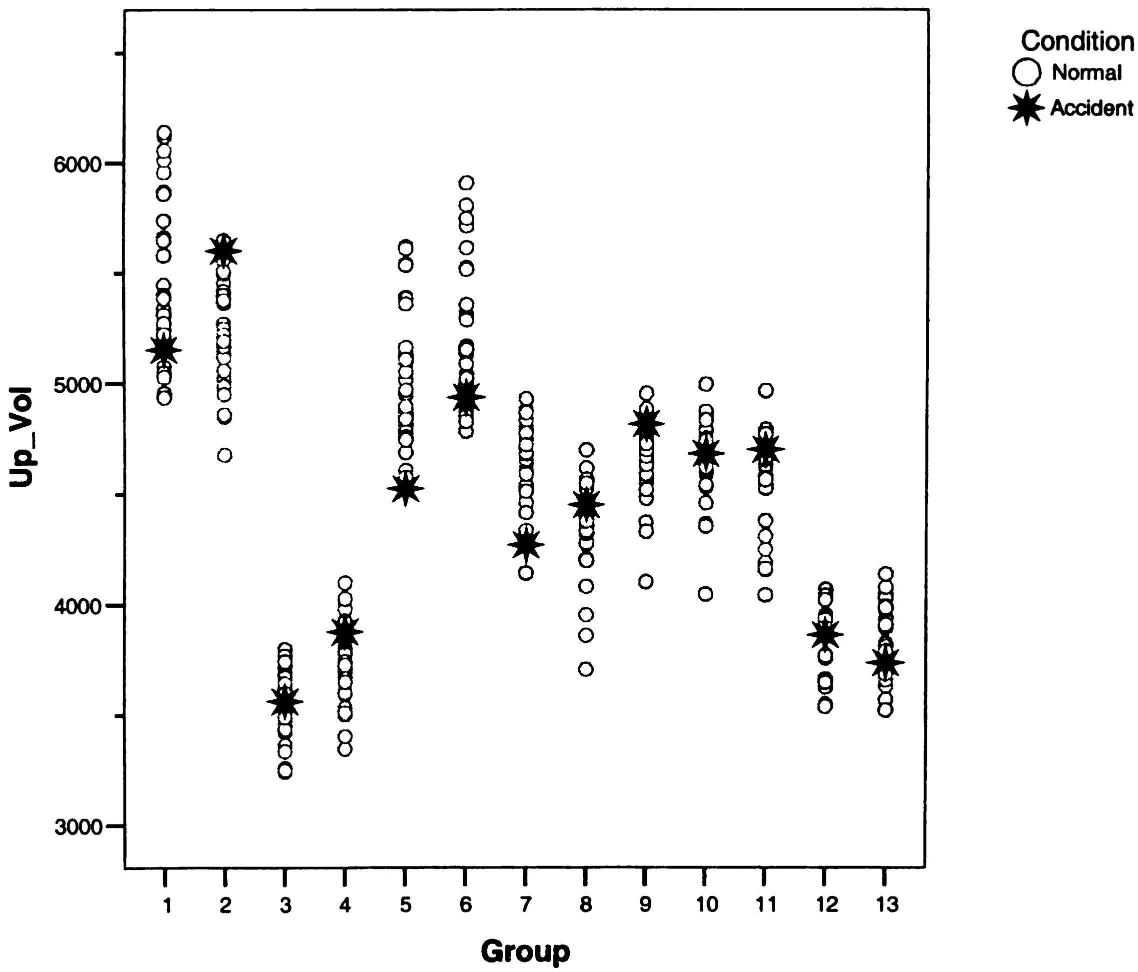


Figure A. 7 Upstream Volume Distribution at Site 5

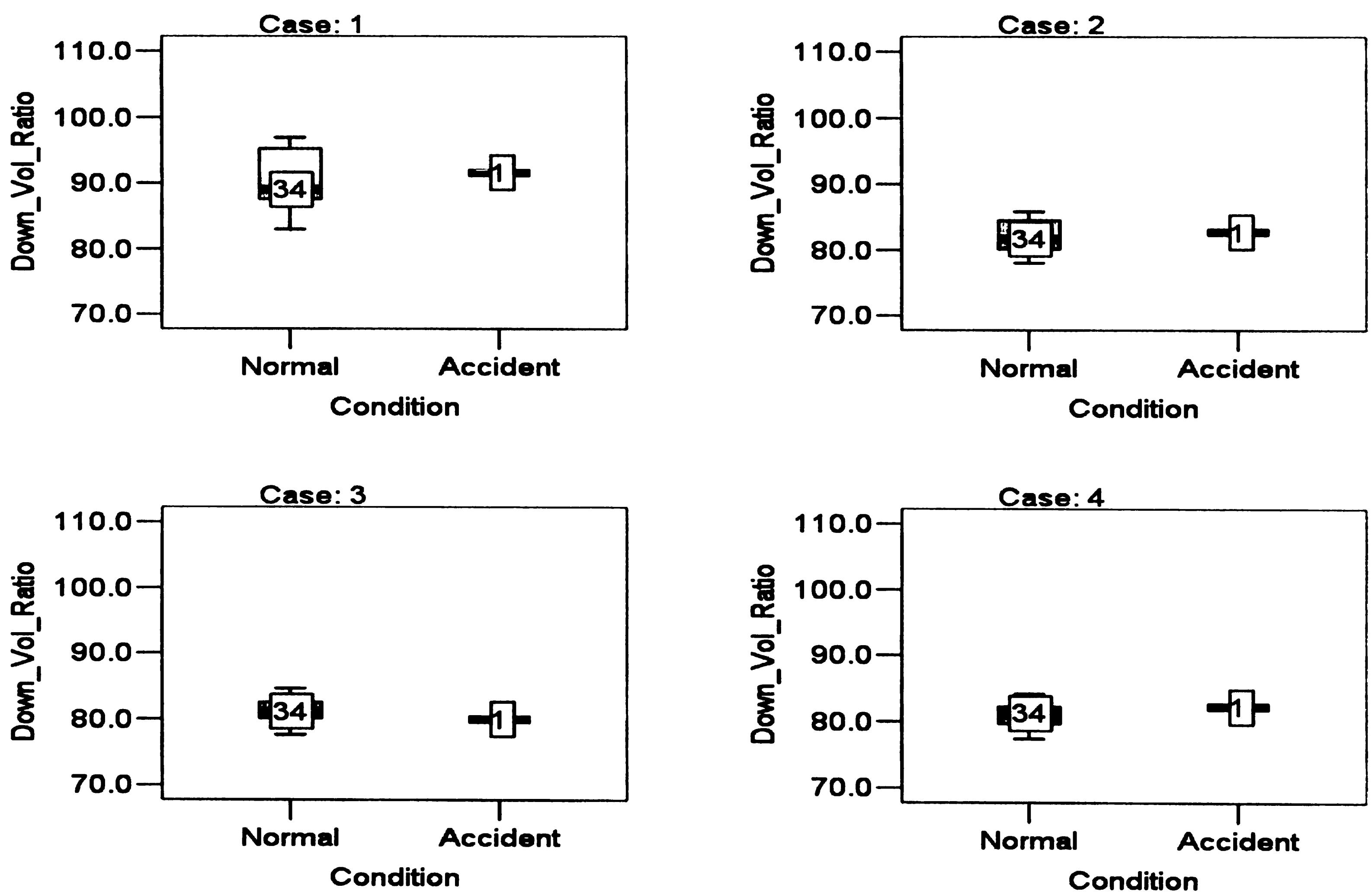


Figure A.8 Downstream Volume Ratio Comparisons at Site 5

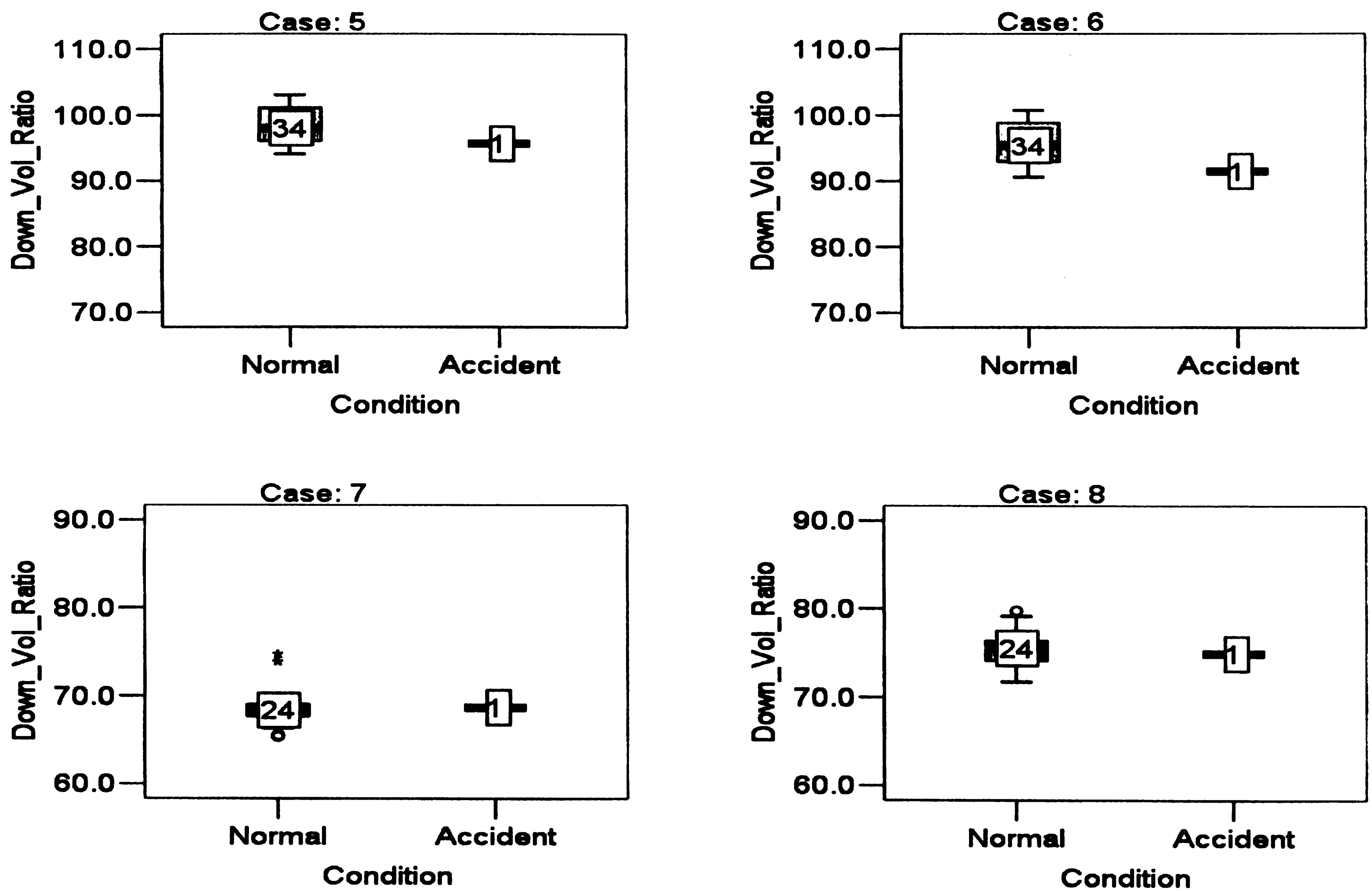


Figure A.8 Downstream Volume Ratio Comparisons at Site 5 (Continued)

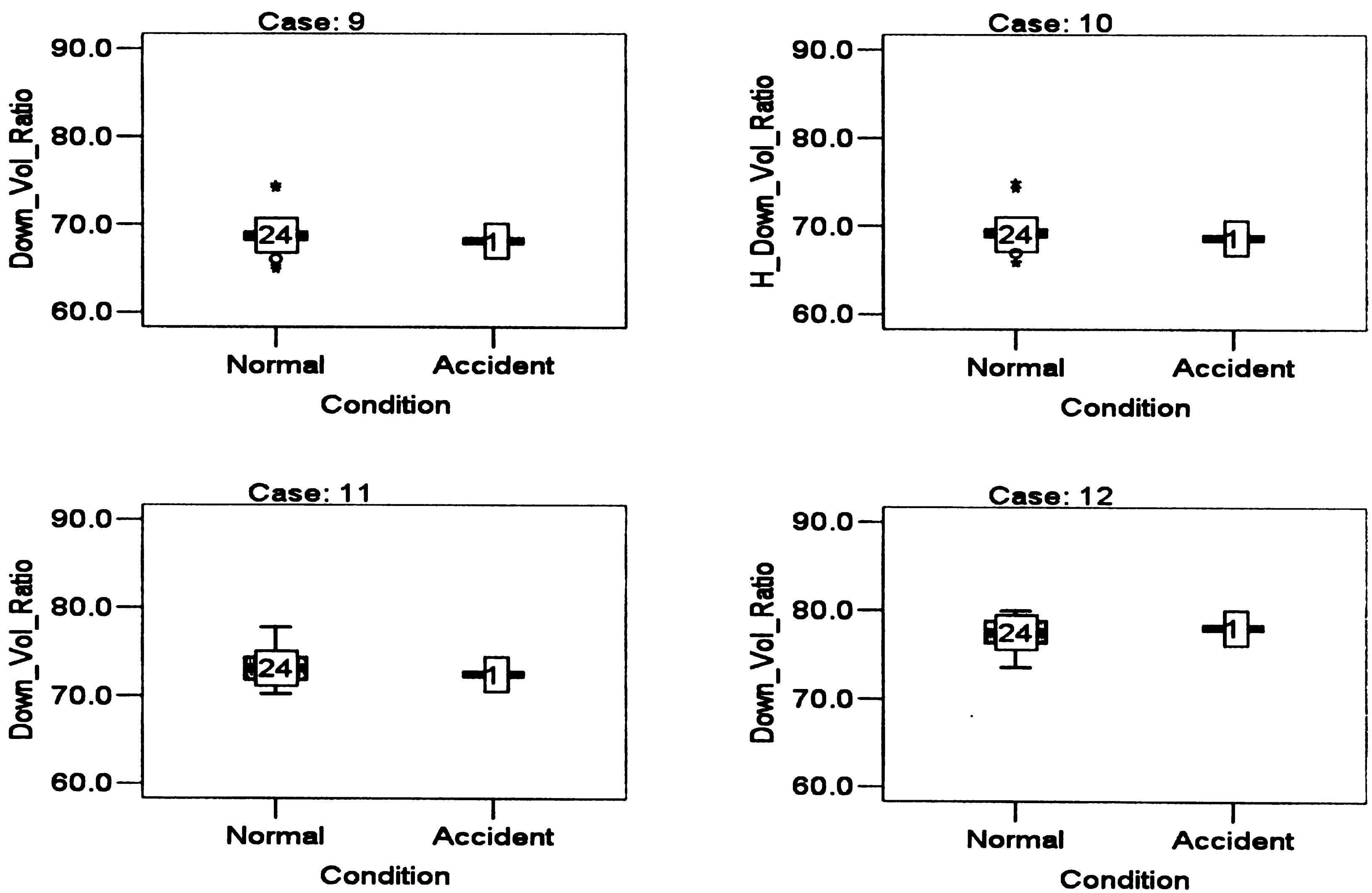


Figure A.8 Downstream Volume Ratio Comparisons at Site 5 (Continued)

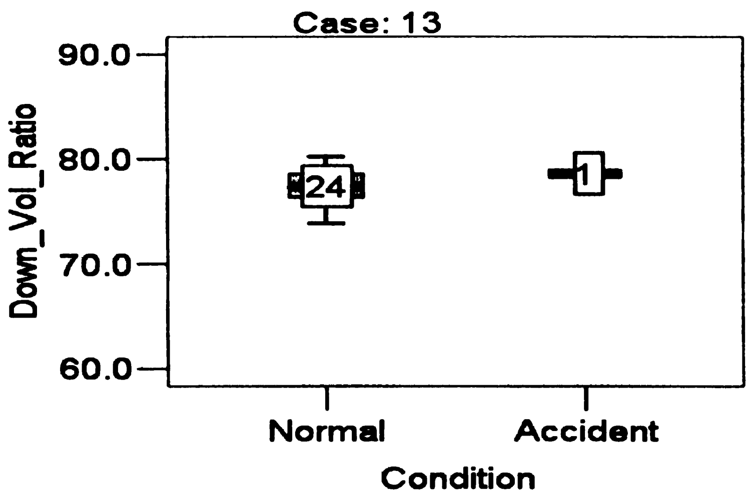


Figure A.8 Downstream Volume Ratio Comparisons at Site 5 (Continued)

REFERENCES

REFERENCES

1. Conrad L. Dudek and Carroll J. Messer, "Study of Design Considerations for Real-time Freeway Information Systems", Highway Research Record 363, Highway Research Board, Washington, D.C., 1971, pp. 1-17.

2. Kenneth W. Heathington, Richard D. Worrall, and Gerald C. Hoff, "Attitudes and Behavior of Drivers Regarding Route Diversion", Highway Research Record 363, Highway Research Board, Washington, D.C., 1971, pp. 18-23.

3. R. Dale Huchingson and Conrad L. Dudek, "Delay, Time Saved, and Travel Time Information for Freeway Traffic management," Transportation Research Record 722, Transportation Research Board, Washington, D.C., 1979, pp. 36-39.

4. R. Dale Huchingson, John R. Whaley, and Nada D. Huddleston, "Delay Message and Delay Tolerance at Houston Work Zones," Transportation Research Record 957, Transportation Research Board, Washington, D.C., 1984, pp. 19-21.

5. Hani S. Mahmassani, Christopher G. Caplice, and C. Michael Walton, "Characteristics of Urban Commuter Behavior: Switching Propensity and Use of Information", Transportation Research Record 1285, Transportation Research Board, Washington, D.C., 1990, pp. 57-69.

6. Edward Daniels, Moshe Levin and Joseph M. McDermott, "Improving Commercial Radio Traffic Reports in the Chicago Area," Transportation Research Record 600, Transportation Research Board, Washington D.C., 1976, pp. 52-57.

7. R. Dale Huchingson, R.W. McNees, and Conrad L. Dudek, "Survey of Motorist Route-Selection Criteria," Transportation Research Record 643, Transportation Research Board, Washington, D.C., 1977, pp. 45-48.

8. Stephanedes, Y., E. Kwon, and P. Michalopoulos, "Demand Diversion for Vehicle Guidance, Simulation, and Control in Freeway Corridors," Transportation Research Record 1120, Transportation Research Board, Washington, D.C., 1988, pp. 12-20.

9. Mannering, F., "Poisson Analysis of Commuter Flexibility in Changing Routes and Departure Times," Transportation Research, Vol. 23 B, No. 1. 1989, pp. 53-60.

10. Decek, C., C. Messer, and H. Jones., "Study of Design Considerations for Real-Time Freeway Information Systems," Highway Research Record 363, Highway Record Board, Washington, D.C., 1971.

11. Elham Shirazi, Stuart Anderson, and John Stesney, "Commuter's Attitudes Toward Traffic Information Systems and Route Diversion," Transportation Research Record 1168, Transportation Research Board, Washington D.C., 1988, pp. 9-15.

12. Roper, D., R. Zimowski, and A. Iwamasa, "Diversion of Freeway Traffic in Los Angeles: It Worked," Transportation Research Record 975, Transportation Research Board, Washington, D.C., 1984.

13. Asad, J. Khattak, Joseph L. Schofer, and Frank S. Koppelman, "Factors Influencing Commuters' En Route Diversion Behavior in Response to Delay", Transportation Research Record 1318, Transportation Research Board, Washington, D.C., 1991, pp. 125-136.

14. Amalia Polydoropoulou, Moshe Ben-Akiva, and Isam Kaysi, "Influence of Traffic Information on Drivers' Route Choice Behavior", Transportation Research Record 1453, Transportation Research Board, Washington, D.C., 1994, pp. 56-65.

15. Asad Khattak, Adib Kanafani, and Emmanuel le Collectter, "Stated and Reported Route Diversion Behavior: Implications of Benefits of Advanced Traveler Information System," Transportation Research Record 1464, Transportation Research Board, Washington, D.C., 1994, pp. 28-35.

16. Samer M. Madanat, C. Y. David Yang, and Ying-Ming Yen, "Analysis of Stated Route Diversion Intentions Under Advanced Traveler Information Systems Using Latent Variable Modeling," Transportation Research Record 1485, Transportation Research Board, Washington, D.C., 1995, pp. 148-154.

17. Mohamed A. Abdel-Aty, Ryuichi Kitamura, and Paul P. Jovanis, "Exploring Route Choice Behavior using Geographic Information System-Based Alternative Routes and Hypothetical Travel Time Information Input," Transportation Research Record 1493, Transportation Research Board, Washington, D.C., 1995, pp. 74-80.

18. Asad Khattak, Amalia Polydoropoulou, and Moshe Ben-Akiva, "Modeling Revealed and Stated Pre-trip Travel Response to Advanced Traveler Information Systems," Transportation Research Record 1537, Transportation Research Board, Washington, D.C., 1996, pp. 46-54.

19. Brien G. Bension, "Motorist Attitudes about Content of Variable-Message Signs," Transportation Research Record 1550, Transportation Research Board, Washington, D.C., 1996, pp. 48-57.

20. Youngbin Kim and Jean-Luc Ygnace, "Like-Flow Evaluation Using Loop Detector Data: Traveler Response to Variable-Message Signs", Transportation

Research Record 1550, Transportation Research Board, Washington, D.C., 1996, pp. 58-64.

21. Aemal J. Khattak and Asad J. Khattak, "Comparative Analysis of Spatial Knowledge and En-Route Diversion Behavior in Chicago and San Francisco: Implications for Advanced Traveler Information Systems", Transportation Research Record 1621, Transportation Research Board, Washington, D.C., 1998, pp. 27-35.

22. Ronald Koo and Youngbin Yim, "Commuter Response to Traffic Information on an Incident," Transportation Research Record 1621, Transportation Research Board, Washington, D.C., 1998, pp. 36-42.

23. Srinivas Peeta, Jorge L. Ramos, and Raghubhushan Pasupathy, "Content of Variable Message Signs and On-Line Driver Behavior," Transportation Research Record 1725, Transportation Research Board, Washington, D.C., 2000, pp. 102-108.

24. Srinivas Peeta and Shyam Gedela, "Real-Time Variable Message Sign-Based Route Guidance Consistent with Driver Behavior", Transportation Research Record 1752, Transportation Research Board, Washington, D.C., 2001, pp. 117-125.

25. Fred Hall, Sarah Wakefield, and Ahmed Al-Kaisy, "Freeway Quality of Service; What Really Matters to Drivers and Passengers?" Transportation Research Record 1776, Transportation Research Board, Washington, D.C., 2001, pp. 17-23.

26. Srinivas Peeta, Kamalakar Poonuru, and Kumares Sinha, "Evaluation of Mobility Impacts of Advanced Information Systems," Journal of Transportation Engineering, June 2000.

27. Jeffrey L. Alder, Wilfred W. Recker and Michael G. McNally, "Using Interactive Simulation to Model Driver Behavior under ATIS," University of California, Irvine, 1992.

28. Conrad L. Dudek, R. Dale Huchingson, and R. Quinn Brackett, "Studies of Highway Advisory Radio Messages for Route Diversion," Transportation Research Record 904, Transportation Research Board, Washington, D.C., 1983, pp. 4-9.

29. Conrad L. Dudek. "Human Factors Considerations for In-Vehicle Route Guidance," Transportation Research Record 737, Transportation Research Board, Washington D.C., 1979, pp. 104-107.

30. Conrad L. Dudek, William R. Stockton, and Donard R. Hatcher, "Real-Time Freeway-to-Freeway Diversion: The San Antonio Experience," Transportation

Research Record 841, Transportation Research Board, Washington, D.C., 1982, pp. 1-14.

31. D.H. Roper, R.F. Zimowski, and A.M. Iwamasa, "Diversion of Freeway Traffic in Los Angeles: It Worked," Transportation Research Record 957, Transportation Research Board, Washington, D.C., 1984, pp. 1-4.

32. Conrad L. Dudek, Graeme D. Weaver, Donald R. Hatcher, and Stephen H. Richards, "Field Evaluation of Message for Real-Time Diversion of Freeway Traffic for Special Events," Transportation Research Record 682, Transportation Research Board, Washington, D.C., 1978, pp. 37-45.

33. Stephen H. Richards, William R. Stockton, and Conrad L. Dudek, "Analysis of Driver Responses to Point Diversion for Special Events," Transportation Research Record 682, Transportation Research Board, Washington, D.C., 1978, pp. 46-52.

34. J. Michael Turner, Conrad L. Dudek and James D. Carvell, "Real-Time Diversion of Freeway Traffic During Maintenance Operations," Transportation Research Record 683, Transportation Research Board, Washington, D.C., 1978, pp. 8-10.

35. Development Traveler Information Systems Using the National ITS Architecture. Report FHWA-JPO-98-031. FHWA, U.S. Department of Transportation, 1998.

36. David Schrank, and Tim Romax, The 2003 Annual Urban Mobility Report, Texas Transportation Institute, The Texas A&M University Systems, 2003

37. Raktim Pal, Investigation on Latent Factors Affecting Route Diversion Intentions, Journal of Transportation Engineering, July/August 1998

38. Michael J. Wenger, Jan H. Spyridakis, Mark P. Haselkorn, Woodrow Barfield, and Loveday Conquest. Motorist Behavior and the Design of Motorist Information Systems, Transportation Research Record 1281, Transportation Research Board, Washington, D.C., 1990, pp159-167.

39. C.L Dudek. Guidelines on the Use of Changeable Message Signs. Report No. FHWA-TS-90-043, May 1991.

40. C.L Dudek. Changeable Message Signs. NCHRP Synthesis 237. National Cooperative Highway Research Program, Transportation Research Board. Washington D.C. 1997.

41. Robert B. Schiesel and Michael J. Demetsky. Evaluation of Traveler Diversion Due to En-Route Information. Report No. UVA/29472/CE00/103, May 2000.

42. http://www.benefitcost.its.dot.gov