A model of driver response to variable message signs as an incident management tool

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A MODEL OF DRIVER RESPONSE TO VARIABLE MESSAGE SIGNS AS AN INCIDENT MANAGEMENT TOOL

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A dissertation submitted in fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Amended copy

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DECLARATION

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ABSTRACT

Traffic congestion is a fast growing problem in large metropolitan areas. Incidents are a major cause of urban network congestion. Thus, incident management remains a prime concern of road authorities worldwide. Although traffic management is a key element in managing incidents, it is most often neglected. The use of VMS is one promising technology for incident management. If drivers' response, in terms of flow diversion, to various VMS messages can be predicted, it may be possible to influence drivers' route choice behaviour using appropriate messages in order to achieve an 'optimum' diversion rate (defined as one that produces the minimum total congestion delay in the surrounding road network).

While several international research studies have developed driver response models to VMS, the proposed models have serious limitations in predicting diversion rates under different conditions and in other countries. The aim of this research is to develop a general route diversion model in response to VMS in Sydney, and to demonstrate its benefits in developing incident management plans.

A stated preference survey was conducted in Sydney Metropolitan Area to collect information on drivers' route choice behaviour in response to various VMS messages and for a broad range of trip characteristics.

From this data a logistic model was developed –which predicts the probability of diversion based on a number of attributes related to the trip, the driver and the VMS message. Model validation using an independent data set showed 15.5% error in the response prediction.

A parametric analysis showed that drivers are more likely to divert with the increase of the displayed delay time on the usual route, the decrease of the travel time difference between the alternative and usual routes in normal conditions and the decrease of trip time.

The prediction model was implemented and verified in SITRAS, a simulation model which enables the analysis of VMS impacts on network performance.

The benefits of the prediction model as an incident management tool were demonstrated in the M2 Hills Motorway case study. Different Incident Management Plans were introduced and the optimum plan was recommended. Finally, recommendations for further research were formulated.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

Traffic congestion in urban areas constitutes a major problem in large cities due to the increase in population, commerce, and development activities. Increase in travel delay, fuel consumption, air pollution, and vehicle operating costs attributed to congestion imposes huge costs on society. For example, the estimated congestion cost in Sydney is at least $2 billion per year (Commeignes 1992).

Several international studies (eg. Grenzeback and Woodle 1992) found that as much as 50 percent of this congestion results from traffic incidents, ie. events that create an unexpected and temporary reduction of road capacity, such as a stalled vehicle, a crash, inclement weather or even a planned roadwork. The traffic congestion that results from these incidents can lead to additional accidents, cause delayed response to emergency situations and reduces the quality of life in a community.

Recognition of the significance of traffic incidents has prompted road authorities to develop and implement Incident Management (IM) plans in many metropolitan areas around the world. The majority of these plans concentrate on early detection and clearance of the incident so as to minimise the effects of incidents. These plans also aim to coordinate the actions of the various institutions involved in the IM plan such as the traffic authorities, police, fire department, tow truck operators, etc. However as indicated by the literature the weakest link in the chain of IM plans is the traffic management during the incident (Judycki & Robinson 1992).

Traffic management during incidents has a substantial effect on reducing the delay associated with any particular incident. Figure 1.1 shows a cumulative traffic flow diagram during an incident. The triangular area, that lies among the lines representing the normal demand flow, incident flow and getaway flow, represents the total delay experienced by traffic due to the incident. The total delay can be minimised by diverting some traffic to alternative route, ie., by reducing normal demand flow. Consequently, the recovery time, which is the time taken for the traffic condition to return to normal, is minimised. Most frequently, the recovery time exceeds the time of the actual lane blockage (Roper 1990). Accordingly, it can be seen that the traffic management is an important component of the incident management.

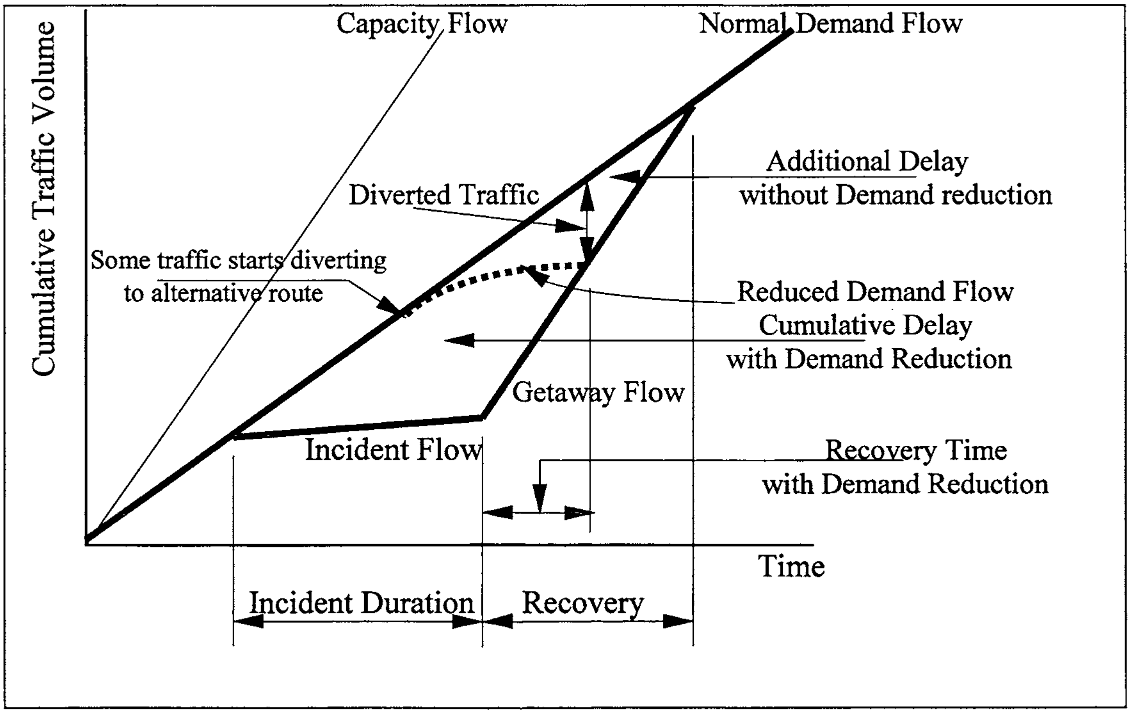

Figure 1.1 Diagram of Traffic Flow during an Incident

One of the most promising traffic management measures during traffic incidents is the use of traveler information systems to inform drivers in real time about the traffic conditions, the presence of incidents, and the expected delay. It is believed that these systems help the drivers to avoid the congestion by diverting from the congested links in the network. One instrument of traveler information systems is Variable Message Signs (VMS), which can be installed beside or above the carriageway, and can be used for various purposes including safety warnings, capacity variation, parking guidance and information, and flow diversion.

Early field studies at VMS locations have found evidence of traffic diversion in the range of 5 to 80 % of the total driver population subjected to the message (Bonsall & Merrall 1995). This range is clearly too wide for prediction and modelling purposes.

In the last decade, several international research studies have been conducted to investigate the influence of various VMS messages on drivers' route choice behaviour and to establish quantitative models of diversion rates (eg. Wardman et al. 1997; Bonsall & Merrall 1995). While these studies provide a better understanding of the factors influencing route choice behaviour in response to real time traffic information, the proposed models have serious limitations in predicting diversion rates under different conditions and in other countries. There is a need to develop more general models for prediction purposes in Australia and to validate such models based on local data. No information of this kind is available in Australia.

1.2 RESEARCH OBJECTIVES

The main objectives of this study are:

- To collect information on drivers' route choice behavior in response to Variable Message Signs for a broad range of trip characteristics in the Sydney Metropolitan Area.
- To develop a general route choice model for predicting diversion rate as a result of the displayed information by VMS.
- To demonstrate the validity and practical use of the model for various trips in the Sydney Metropolitan Area.
- To incorporate the route choice model in an urban network simulation model to study the effect of VMS on the overall network performance under different incident scenarios.
- To assess the benefits of using VMS as an incident management tool through a case study.

1.3 STRUCTURE OF THE THESIS

The research work is presented in this thesis in eight chapters.

Chapter one presents the introduction to the work which includes background, the research objectives, and structure of the thesis.

Chapter two offers a general review to driver information systems and the route choice process in normal conditions as well as in presence of information systems. This chapter also provides a review of the different approaches used in investigating driver behaviour in the presence of information, in addition to the different simulation/assignment models that can be used to evaluate the variable message signs impacts on networks.

Chapter three describes the design of the survey, the survey work, and the data processing. Also, it describes the analysis of the collected data, which includes the sample characteristics and the effect of different factors on the diversion rate.

Chapter four presents the model development which describes the subsequent steps of the data analysis including the model formulation, model building and testing of the model fit. Also, it describes the model validation and provides interpretation of the model coefficients.

In Chapter five, the effect of the different explanatory variables of the developed model on the percent of diversion was analysed.

Chapter six describes the SITRAS simulation model, the implementation of the developed VMS model into SITRAS, and the verification of the VMS model implemented in SITRAS.

Chapter seven presents an assessment of the VMS as an incident management tool through the M2 Hills Motorway case study.

The last chapter, Chapter eight, includes a summary, conclusions, the contribution of the research project, and future work.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a general review to driver information systems and the route choice process in normal conditions as well as in presence of information systems. Also, it reviews the different approaches used in investigating the drivers' behaviour in the presence of information, in addition to, the different simulation/assignment models that can be used to evaluate the variable message signs impacts on networks.

Several methods have been utilised to investigate the drivers' route choice behavior when affected by the information systems. These methods include field surveys, revealed preference approach, stated preference approach, interactive route choice simulators and driver behavior modeling.

Evaluation the VMS information impacts and assessing their benefits on the network performance can be achieved through the detailed simulation/assignment models. Two types of models are commonly used in the urban traffic simulation. These types are macroscopic and microscopic simulation models. Macroscopic models group vehicles into flow and apply the flow relationships to determine successive traffic state. On the other hand, microscopic models calculate the state of the system on the basis of individual drivers and vehicles and their interactions.

2.2 ROUTE CHOICE PROCESS

Route choice is a result of the drivers' decision-making process. The decision-making process consists of finding the available alternative routes and choosing a particular route among them. Each driver decides which route he/she selects based on his/her point of view and the available information to him/her. This decision is a rational behaviour since it relates to a certain driver and changes for different drivers for the same trip. The objective of the driver is to satisfy his/her travel needs while utilising the available alternatives to him/her. Thus, the selected route results from the personal characteristics of the driver and those of the transport system. These characteristics are the basic input to the route choice process as shown in Figure 2.1. The route choice can be explored by carrying out a correlation analysis between the driver and the network characteristics, the input, and the chosen route, the output of the black box, in various situations. While this analysis is accepted to explore the route choice behaviour, it is recommended to obtain knowledge of the inner functioning of the black box (Bovy & Stern 1990).

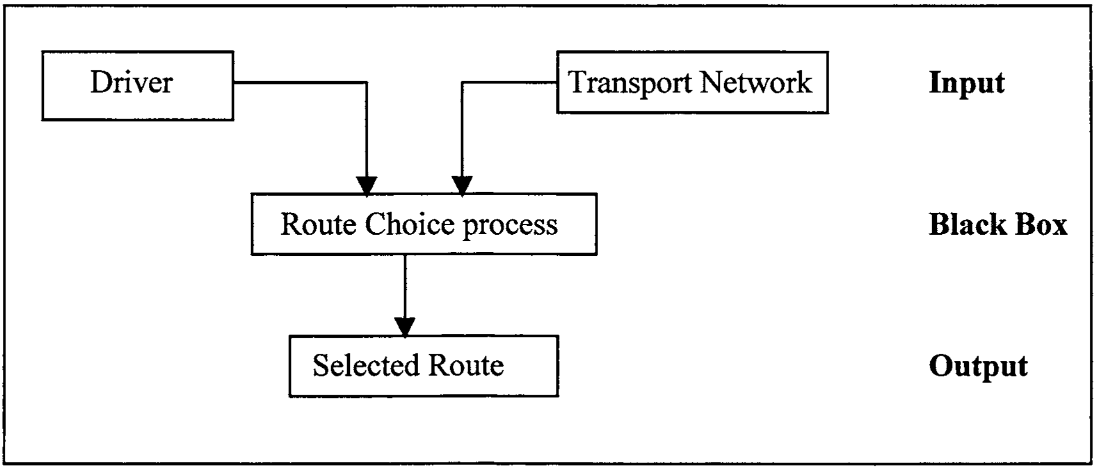

Figure 2.1 General Scheme of Route Selection (Bovy & Stern 1990)

The black box, which is a model of the mind, is the behavioural interface between the man and the environment. The psychological variables intervening between the environment and human behaviour in this model are a mixture of cognitive and affective attitudes, emotions, perceptions, cognition and learning. Accordingly, route choice is concerned with the driver with his/her subjective needs, perceptions, experience, and preferences; and the physical environment with its objective alternatives and their characteristics (Bovy & Stern 1990).

Each driver has only limited knowledge (cognition) of all the routes available. This knowledge is associated with the driver experience, which is a feedback from usage of chosen routes, and his/her way of getting information as using maps and asking others. Also, the driver does not always consider all the available alternative routes because some of them may not meet his/her travel needs, e.g. need for a petrol station enroute (Bovy & Stern 1990).

Each driver chooses the route, from the considered alternatives, based on his/her own perception of the characteristics of these alternatives. As the drivers' perception of the alternative characteristics is sometimes inaccurate, the image of the actual situation will be distorted. Also, the importance of the characteristics differs from one driver to another. Thus, drivers give different weights for the same characteristics (Bovy & Stern 1990).

The route choice process can be considered as a system of two filters: a perception filter and an evaluation filter. Through the perception filter the driver has cognition of the existence of alternative routes and their characteristics. These perceptions with the driver characteristics are transformed through the evaluation filter to a preference and then a choice (Bovy & Stern 1990).

2.2.1 Factors Affecting Route Choice Behavior

Route choice behavior is affected by many factors. Bovy and Stern (1990) classified these factors into four major categories as follows:

- The attributes of the available routes: road characteristics, traffic conditions, and environmental aspects.
- The driver characteristics: age, sex, income, education, and driving experience.
- The trip characteristics: trip purpose, and travel time.
- Other circumstances: weather conditions, time of day, and road and traffic information.

Drivers choose their routes based primarily on the attributes of the available routes. The other three categories are only affect the relative importance and perception of the route attributes.

Thomas (1991) presented many factors that can affect the route choice behavior such as trip length, time and cost, familiarity with the routes, signposting, frequency of traffic signals and roundabouts, queuing, age and sex. Also, Thomas concluded that, there is no clear view for the appropriate factors to be used in choosing the route. On the other hand, the most widely used criterion for the route choice is the travel cost, which contains two attributes: time and monetary cost which proportional to the travel distance (Thomas 1991; ed. Hensher & Button 2000).

2.3 DRIVER INFORMATION SYSTEMS

The objective of the driver information systems is to provide drivers with useful real-time information which otherwise can not be obtained easily. This information includes status messages about incidents, accidents, delays, and weather conditions; and advisory messages on route guidance. Driver information can be provided by three main systems: news/traffic bulletins broadcasting on radio which provide drivers with information before and during the trip, in-vehicle route guidance, and variable message signs (OECD 1987).

2.3.1 Traffic Information Broadcasting Systems

Traffic reports on radio provide drivers with dynamic information on incidents such as roadworks, congestion and accident; and bad weather conditions. This information may affect the driver decision either by re-planning the trip before driving or changing route while driving. The traffic information broadcast by radio is general since it caters to drivers in a certain region while it can be expected to reach a wide range of audience (OECD 1987).

The highway advisory radio, HAR, is a special broadcasting service in the USA. HAR provides drivers with real-time traffic conditions for the roads in the area they are driving in and describes the alternative routes around the congestion areas (OECD 1987).

2.3.2 In-Vehicle Route Guidance Systems

An in-vehicle route guidance system is primarily a dynamic map display fitted in the car indicating the destination and the vehicle position on a map which moves as the car moves. In this system, drivers are required to input their origin and destination before driving through a keyboard. This system also provides drivers with efficient route guidance while driving. The most advanced types of this system have a communication link between the in-vehicle guidance equipment and an external system, which provides real-time traffic information. These types can account of real-time traffic conditions and provide drivers with the suitable route guidance for the prevailing traffic conditions (Bovy & Stern 1990; Underwood et al 1994).

2.3.3 Variable Message Signs (VMS)

Variable message signs have been installed at the roadside in many countries for many years as a means of communicating with drivers. These displays can be used for various purposes including safety warnings, speed restrictions, parking guidance and information, and flow diversion. Variable message signs are increasingly used to provide drivers with information in an attempt to encourage better use of the network.

VMS information reaches all the drivers approaching it. Thus, it can be used in real-time to cause drivers to divert to less congested routes and avoid incident routes. Wardman et al (1997) found that, the provision of VMS information about traffic conditions ahead strongly affect the route choice behaviour. Furthermore, the use of variable message signs to influence drivers' route choice to minimise the impact of any loss in capacity is an area of great current interest worldwide (Wardman et al 1997; Bonsall et al 1998). For these reasons, this research focuses on studying the effect of VMS information, as an incident management tool, on the drivers' route choice behaviour and on the overall network performance.

2.4 Route Choice Behavior in the Presence of Information Systems

The basic route choice behaviour is based on static information as mentioned earlier. This behaviour can be modified by providing drivers with dynamic, real-time, information. The dynamic information helps the drivers to update their cognition, which is transformed to a preference and then a choice depending on drivers' characteristics. The route choice process with the effect of real-time information can be summarised as in Figure 2.2.

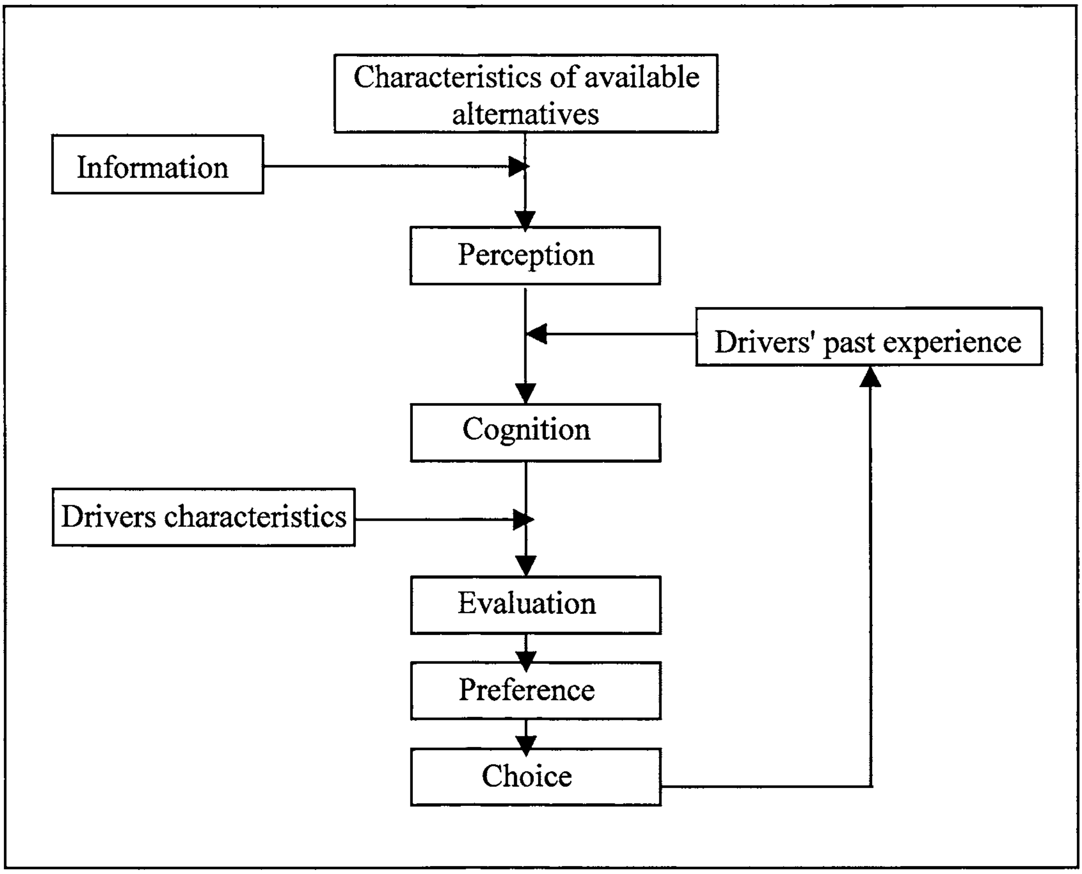

Figure 2.2 Route Choice Process in the Presence of Real-Time Information (Khattak et al 1993a)

The drivers' route choice behaviour in presence of information systems has been investigated using five approaches. These approaches include the field surveys, revealed preference approach, stated preference approach, interactive route choice simulators and driver behaviour modeling. Field surveys are based on observing the real-life behaviour of drivers in response to different information, while the revealed preference approach is based on the reported behaviour by drivers which concerns actual trips previously made in real-life situations. In the stated preference approach, each driver states how he/she would behave in response to hypothetical scenarios. Route choice simulators provide a computer-based road network through which each driver makes a series of journeys, selecting his/her preferred route from each intersection he/she comes to. These methods are described in the following sections.

2.4.1 Field Surveys

Field surveys are usually conducted by measuring the changes in traffic volumes on alternative routes downstream of the VMS site for each displayed message. Also, it is required to collect data on the destinations of the involved vehicles in order to determine the characteristics of the available alternative routes (Bonsall & Palmer 1998).

Traffic volume changes can be measured using the registration plate survey on the alternative routes downstream the VMS site and at the destination. On the other hand, the vehicles' destination can be obtained by means of roadside interviews downstream the VMS site.

Field surveys are an accurate method to understand the effect of information on the driver behaviour since the collected data is for real decisions in real traffic situations. But, this type of surveys yields results for a limited set of messages in a limited range of circumstances. Also, field surveys are relatively expensive and there are no convenient sites for conducting the interviews without disrupting the traffic (Bonsall et al 1998). Accordingly, the field surveys require coordination and cooperation among various authorities that is hard to achieve.

2.4.2 Revealed Preference Approach

Researchers at the University of Washington conducted a survey on the commuter drivers of a specific freeway corridor in Washington. The driver information systems available for this corridor included: radio traffic information, variable message signs, and highway advisory radio. The purpose of this survey was to collect data about commuter drivers' behaviours, particularly the potential for changing these behaviours through the design and delivery of driver information. The survey consisted of two main parts: a large scale mail-back survey distributed on the road followed by a small in-person survey. The large-scale survey was conducted by distributing 10000 questionnaires at eight off-ramps, along the corridor, during the morning peak of two weeks in September 1988. A total of 3893 questionnaires were returned by November 1988. Each questionnaire consisted of four parts: the commuter characteristics, the drivers' route choice and behaviour, the delivery of traffic information, and descriptive data for driver classification (Spyridakis et al 1991).

Spyridakis et al (1991) found that commuter drivers rely on the radio or variable message signs rather than any other source of information. Traffic information, congestion, and the time of day affect the drivers' propensity for diversion. In addition, commuter drivers are more willing to change their usual routes from work rather than from home. Males and commuter drivers who are familiar with the alternative routes are also more likely to divert from the usual routes.

Khattak et al (1991, 1993a) collected data using both the revealed and stated preference approaches through a survey of downtown Chicago commuters. For major routes serving downtown Chicago area, real-time radio traffic information was available. The purpose of the survey was to investigate the effect of real-time traffic information along with other factors on the drivers' willingness of diversion from the usual route during incidents. This survey was conducted by distributing 2000 mail-back questionnaires to the commuter drivers during the morning peak period of April 1990. A total of 700 questionnaires were returned indicating a 33 percent response rate. The data collected from each respondent consisted of four main parts: description of the trip characteristics, details of the previous delay experience and the associated diversion, the attributes of both the usual and alternative routes, and a serious of hypothetical questions about diversion.

Khattak et al (1991, 1993a) found that drivers are more willing to divert in response to radio traffic information rather than from their own observations of delay. Drivers who have longer trips and facing longer delays are more likely to divert from the usual route. Also, the commuter drivers are more likely to divert when they are males, familiar with the alternative routes and living in the city rather than the suburbs.

Khattak et al (1994) used the same data to evaluate the effect of real-time radio traffic information on the drivers' propensity of diversion and changing departure time. It was found that the traffic information has a strong effect on the drivers' willingness to divert and to change the departure time. Higher income commuters and males are more likely to divert. Also, the commuter drivers who are familiar with the network are more willing to divert. The commuter drivers are more likely to change their routes and departure times if they receive accurate traffic information about their usual route delays and listen to the information more frequently. In addition, the drivers' willingness to change their departure times increases with the decrease of the difference in travel time between the usual and alternative routes. On the other hand, the socio-economic characteristics and the flexibility in arrival time do not affect the departure time.

Abdel-aty et al (1994) analysed the drivers' route choice behaviour and the effect of traffic information based on a survey of Los Angeles area commuter drivers. The survey was conducted using computer-aided telephone interviews for 944 commuters in May and June 1992. The main purpose of the survey was to investigate the drivers' knowledge about their usual and alternative routes, the traffic conditions that could affect their route choice behaviour and their response for the available traffic information.

Abdel-aty et al (1994) concluded that the most common factors for diversion from the usual route are: reducing travel time, receiving traffic reports, time of leaving home, increasing income and education levels. Higher income, higher education level, and higher frequency of driving to work and frequency of listening to traffic information increase the willingness for diversion. Also, women and long distance commuters are more likely to listen to the pre-trip traffic information.

Uchida et al (1994a, 1994b) conducted a panel survey, between April 1991 and September 1993, to analyse the effect of the travel time information displayed by variable message signs on drivers route choice behavior. The survey was conducted by distributing questionnaires to drivers near the variable message signs locations and mailing the same questionnaires to the drivers (i.e. this survey consisted of both an on-road survey and a panel survey by mail). Panel surveys were conducted to pursue drivers who responded to on-road surveys. Each questionnaire contained five main parts: respondent attributes, trip attributes, route choice, influence of travel time information, and strategic choice which included: normal tendencies of route choice, previous usual route, recent usual route, and the degree of dependence on travel time information.

Uchida et al (1994a, 1994b) found that, the drivers are very interested in the travel time information and they evaluate the usefulness of the information positively. Also, they are more willing to divert from the usual route in response to the travel time information. The drivers' attributes do not always affect the route choice behavior.

Emmerink et al (1996) used the data collected from the survey, conducted by the participants of the EC DRIVE II project BATT, to analyse the effect of both radio traffic information and variable message signs on drivers' route choice behaviour. This survey was conducted by distributing 2145 questionnaires to the road users of the Amsterdam ring-road at four petrol stations, in the third week of July 1994. A total of 826 questionnaires were returned by post, indicating 38.5% response rate. Each questionnaire consisted of four parts: the travel characteristics, the use and effect of radio traffic information, the use and effect of variable message signs, and the socio-economic characteristics.

Emmerink et al (1996) found that the effect of radio traffic information and the variable message signs information on the route choice behaviour are very similar. Women and commuters are less willing to divert from the usual route in response to the traffic information. Flexibility of arrival time does not affect the willingness for diversion in response to radio traffic information but decreases the probability of diversion in response to variable message signs. The type and distance of the alternative routes affect the willingness for diversion.

Benson (1996) conducted a survey through computer-assisted telephone interviews in Washington DC area to investigate the effect of the content of variable message signs on the drivers behavior. A total of 517 interviews were conducted. A key finding of this study is that demographic variables have little effect on drivers' response to variable message signs. Also, respondents were disposed toward a new type of variable message signs that contains simple, reliable and useful information.

Koo and Yim (1998) investigated the effect of incident information on drivers' route choice behavior based on a survey conducted on commuter drivers of a certain freeway corridor in San Francisco Bay area. The incident information available to this area can be obtained by dialing a certain phone number. The survey was conducted using phone interviews immediately after the occurrence of a major highway incident on that corridor during the morning peak hours. The collected data consisted of four parts: the incident related information and its effect, the respondent behaviour, and the demographic characteristics of the respondents. The results showed that, a fair proportion of the commuter drivers obtained the incident information but they were not willing to divert in response.

Dia et al (2000) conducted a survey, using both revealed and stated preference approaches, to investigate factors affecting both the drivers' willingness of diversion and changing departure time in response to real-time information. The survey was conducted by distributing 490 mail-back questionnaires, during the morning and afternoon peak periods, to commuter drivers on a congested corridor in Brisbane. Two questionnaire forms were distributed, the first for the pre-trip information while the second for the en-route information. A total of 167 questionnaires were returned, indicating 34% response rate, including 82 for pre-trip and 85 for en-route information.

Each questionnaire contained four parts; three of them are similar for both the pre-trip and en-route questionnaires. These parts are: personal information, normal travel patterns, and willingness to change driving patterns. The last part is the pre-trip response to unexpected congestion information for the pre-trip questionnaires, and is the en-route response to unexpected congestion information for the en-route questionnaires.

Dia et al (2000) concluded from the preliminary results that, young drivers and those with flexible arrival time to work are more likely to divert from the usual route when provided with delay information. On the other hand, females are less likely to divert in response to traffic information.

2.4.3 Stated Preference Approach

Brocken and Van der Vlist (1991) conducted a stated preference survey to investigate the route choice behaviour in congested motorway networks to help in designing a VMS-system on the Ring Road around Amsterdam. In the stated preference survey, each respondent had to choose between two different routes each having their own specific values of distance and delay. Also, a number of questions concerning the socio-economic characteristics as well as the usual work trip were asked. Brocken and Van der Vlist (1991) found that the average commuter is willing to diverge 12.4 km for every 10 minutes of congestion delay (ie. the average commuter is willing divert when the travel time on the alternative route is 2.4 minute longer than on the original route with a speed of 60 km/hour). Furthermore, the journey and socio-economic characteristics do not affect the route choice behaviour.

Khattak et al (1993b) used data previously collected from a survey of Downtown Chicago commuters to investigate the effect of real-traffic information along with drivers characteristics, road characteristics and situational factors on the commuter drivers' willingness to divert. The analysis of data showed that, drivers are more willing to divert in response to incident congestion rather than recurring congestion and in response to radio traffic information rather than from their own observations of delay. In addition, drivers who have longer travel times, facing longer delays and driving from home to work are more likely to divert from the usual route. Higher income drivers and the commuter drivers who are familiar with the alternative routes are also more likely to divert.

Hato and Taniguchi (1994) conducted a stated preference survey to analyse the effect of variable message signs' information on the drivers' route choice. In this survey, the drivers were assumed to be driving on the Metropolitan Expressway in Japan or alternative surface roads, and they asked to choose their route based on hypothetical travel time information displayed to them. This survey was conducted in May 1993 and the number of respondents was 2520.

Hato and Taniguchi (1994) found that the traffic information has a strong effect on the drivers' route choice; drivers are willing to divert as a result of the traffic information. In addition, the experienced drivers are more willing to divert than the inexperienced.

Iida et al (1994) conducted a stated preference experiment to investigate the effect of providing travel time information on the drivers' route choice. In the experiment, the drivers were asked repeatedly to select a route, from a simple hypothetical network, in response to travel time information. Iida et al (1994) found that, the route choice depends on the quality of the travel time information.

Wardman et al (1997) conducted a stated preference survey to undertake a detailed assessment of the effect of information provided by variable message signs, VMS, on drivers route choice for a trip of 34 km length between Warrington and Manchester City Centre. The survey was conducted by delivering 900 questionnaires to households in summer 1995. A total of 314 questionnaires were returned indicating 34.9% response rate. The respondents were asked to indicate which route they would select if they see a VMS displaying information about traffic conditions ahead while they are driving. The displayed information included different causes and duration of delay.

The stated preference approach was used for this study since it has many attractions. Firstly, the ability of the stated preference approach to control the choice context and the independent variables that will enter the route choice model and these features are particularly important to the analysis of the impact of VMS on drivers route choice. Secondly, the stated preference (SP) experiment offers decision-makers a series of hypothetical scenarios to be evaluated. Thus, in the SP surveys, data can be collected for a wide range of messages in a wide range of circumstances. The respondents can be asked about the route they would select if faced with each of a series of VMS's in a series of circumstances. Finally, the stated preference approach allows to design questions about the drivers' journey rather than a hypothetical journey.

The potential shortcoming of the stated preference approach is related to the fact that individuals are not committed to behave in accordance with their SP responses.

Wardman et al (1997) found that the value, perceived by the drivers, of the displayed delays on the VMS, in minutes is larger than the travel time with ratios between 1.3 and 1.7 depending on the displayed cause of delay. The perceived values of the VMS message 'long delays' were between 35 and 47 minutes while for 'delays likely' were between 10 and 31 minutes depending on the displayed cause. Also, it was found that drivers are more willing to divert if the displayed cause of the delay is accident rather than roadworks or no cause. On the other hand, younger and female drivers are less likely to divert in response to VMS information. Visible queues have significant effect on route choice, particularly for experienced drivers and for those who believe that VMS's are not reliable.

Abdel-Aty et al (1997) used data collected from two stated preference surveys to investigate the effect of traffic information and travel time variability on the route choice behaviour. The first survey was conducted using computer-aided telephone interviews of Los Angeles commuters in May 1993 which yielded 564 completed interviews. In this survey, five stated preference choices were included, in each, respondents were asked to choose between two hypothetical routes. The first route has fixed travel time every day while the travel time on the other may increase in some days. The travel time of the first route was always longer and certain (fixed), while that of the other route was shorter but uncertain. The second survey was conducted by sending 263 mail-back questionnaires to the respondents of the previous surveys who agreed to provide their address in October 1993. A total of 143 questionnaires were returned indicating 54.4% response rate. In this survey, each respondent was provided three scenarios. In each scenario, respondents were asked to choose between two routes, their primary route and a hypothetical route. Respondents were provided with traffic information which included the travel time and cause of delay.

Abdel-Aty et al (1997) found that, the respondents are more likely to divert with the increase of the difference in expected travel time between the usual and the other route. In addition, the traffic information is more likely to affect the route choice behaviour. Males and younger drivers and commuters with longer trips are also more likely to divert. It was suggested that the traffic information should focus on providing the commuter drivers with information rather than giving advice.

A stated preference survey was conducted in CLEOPATRA, a telematics project in the European Commission's Fourth Framework programme, to evaluate the effect of the variable message signs on the drivers' route choice in a certain corridor in London. The network impacts of variable message signs was evaluated using RGCONTRAM, which is a traffic assignment model. The survey was conducted by distributing two thousand self-completion questionnaires to drivers on December

1997. A total of 246 questionnaires were returned indicating 12.3% response rate. Each questionnaire consisted of four parts: the drivers' characteristics, details of journey being undertaken, scenarios for unexpected congestion in which drivers were asked whether they divert or not when facing with queues, and scenarios for different variable message signs in which drivers were asked about the route they would select in response to five different variable message signs (Hounsell et al 1998; Chatterjee et al 1998, 2000).

Hounsell et al and Chatterjee et al (1998) found from the initial results that if drivers stay on their usual route, the drivers on the incident link experience large delays but other drivers are hardly affected. Also, all drivers will have little delays if they have perfect knowledge of the network conditions and that is far from the real life.

Chatterjee et al (2000) concluded, from the logistic regression analysis of data, that the probability of diversion increases if the incident displayed on the variable message sign occurs on the usual route. Also, drivers are more willing to divert with the increase of the displayed delay time and when the displayed delay is long delays rather than delays. On the other hand, the probability of diversion decreases when the incident is further away from the variable message, and if the incident displayed on the variable message sign is congestion. In addition, the probability of diversion decreases with the increase of the trip length prior the variable message sign location.

Chatterjee et al (2000) also found that, the extra travel distance/time to reach the destination using the alternative route instead of the usual route in normal conditions does not have significant effect on the probability of diversion. A possible explanation is that the extra travel time of most of the respondents, 77%, was 5 minutes or less.

2.4.4 Interactive Route Choice Simulators

Bonsall and Parry (1991) developed an interactive route choice simulator called IGOR to analyse the drivers' reaction to route guidance and information. In IGOR, each participant is asked to make a number of journeys, in front of a PC screen, through hypothetical networks by progressing from one junction to the next. At each junction, the participant is shown a plan of the junction, associated with contextual information, and is asked to indicate which route he/she would select. On some of the journeys, a route guidance advice is shown to the participant and he/she can ignore it if desired. IGOR programmed to display a given amount of bad advice to check the effect of the quality of advice.

Each participant makes several journeys from specified origins to specified destinations. Before the first journey, the participant is asked to provide a certain amount of personal information as age, sex, distance driven per year, whether drive to work, and car ownership. After completing the last journey, participants are presented with 6 stated preference questions in which they should state which of two routes they would select in each of 6 specific situations. After that, participants are asked some attitudinal questions on the perceived usefulness of guidance and on the user's normal route choice criteria. IGOR provides drivers with feedback on the consequences of their own decisions but does not consider supply side response nor the consequences on other drivers, it is purely a device for collecting data on drivers' response to certain situations.

Bonsall and Parry (1991) found that, acceptance of an advice increases with the increase of its quality, and the quality of previously received advice. On the other hand, women and drivers familiar with the network are less willing to accept the advice than others are.

IGOR has proved to be a very valuable tool to examine route choice. But, a realistic model of route guidance or information systems must incorporate a representation of the demand-side as well as on the supply-side (Bonsall & Parry 1991).

Bonsall (1994a) participated in developing a route choice simulator called VLADIMIR, which is a PC-based programme, to explore the effect of in-vehicle and variable message signs information on route choice behaviour. The design of VLADIMIR included some desirable improvements, based on the experience with IGOR. A VLADIMIR screen consists of three parts: a through-the-window view, a dashboard and space for an intersection plan. As the participant moves through the network he/she sees, on the windscreen, an appropriate sequence of photographs with text to show the traffic conditions. The speed, time and distance travelled are shown on the dashboard. When an intersection is reached, a plan of it appears and the participant has to choose which route he/she would use. In VLADIMIR the in-vehicle information is displayed on the dashboard while the variable message signs are displayed through the windscreen. VLADIMIR can be made to represent any real network.

Bonsall (1994a) found that, the route choice simulators are an ideal tool for understanding drivers route choice in the presence of guidance and information but, they must clearly be used with considerable care and not applied to problems to which they are not suited.

Bonsall (1994b) collected data using VLADIMIR to investigate the effect of a range of VMS messages on drivers' route choice in Central Scotland and around Aalborgin, Denmark. Each participant was asked to make a series of journeys to given destinations without displaying VMS information and then to repeat them with the provision of VMS messages. After finishing the journeys, participants were asked a series of questions about their real life route choice criteria and network familiarity, their previous experience of VMS, their personal characteristics and their assessment of the realism of the exercise.

Analysis of the data from VLADIMIR can identify messages which are effective or non-effective in changing drivers' routes and can offer reasons as to why this might be. Also, the analysis can indicate whether particular types of drivers have problems with particular messages and can develop equations to predict the effectiveness of a particular message in a particular situation (Bonsall 1994b).

Bonsall (1994b) found that the effect of signs increases with the quoted delay. Also, the effect of the signs increases by mentioning the reason of the delay in addition to the delay length. A message giving advice without information has less effect than one that gives information without advice. In addition, the effect of messages mentioning roadworks is less than those mentioning accidents.

Bonsall and Merrall (1995) collected data, using VLADIMIR, on the effect of VMS information on drivers' route-choice behaviour. The data was collected for two networks; one urban, in the town of Aalborg in Denmark, and the other interurban, in central Scotland. Each participant was asked to make every journey once without displaying VMS information and then with the provision of VMS messages. A total of 457 persons participated in the survey, 284 in Denmark and 173 in UK, yielding more than 20,000 data points on route choice behaviour. The displayed information on each VMS included one or more of the following items: location of an incident on the network, nature of the incident (roadworks, accident, queues), warning of delay at certain location, estimate of delay at certain location, and recommended route to certain destination.

From the preliminary analysis of data, Bonsall and Merrall (1995) concluded that the effectiveness of an individual message for diversion depends on: the extra travel time of the diversion route in normal traffic conditions, and the existence of potential diversion points further downstream. In addition, the displayed delay, its cause, and whether a diversion is recommended, as well as the driver characteristics have an effect on the diversion. It was also found that, messages displaying roadworks have less effect than those displaying an accident (other things being equal). Furthermore, the greater the quoted delay the more effective the message will be. The statistical analysis of the data has shown that the responses to the same VMS message changes significantly with changes in drivers' familiarity with the network.

Bonsall and Palmer (1998) used data previously collected by VLADIMIR in Denmark, Scotland and Leeds to explore the effect of the content and phrasing of the VMS message. The results showed that, messages giving advice without information have less effect than those giving information without advice. The effect of the unquantified delays such as "delays" and "long delays" varies due to the VMS location. Messages describing minor problems may affect the drivers route choice if the displayed delay is perceived as less serious than the normal condition. Combinations of cause, length of delay and route advice are particularly effective, but the mention of roadworks reduces the diversion rate. The effectiveness of a particular message depends on the proportion of the passing drivers for whom it is relevant, the relative attractiveness of the potential diversion route, the local traffic conditions and the characteristics of the drivers. The most important driver characteristic is the level of familiarity with the network.

Bonsall et al (1997) described validation experiments for the VLADIMIR route choice simulator. Each experiment involved a comparison of routes selected in real life with routes driven under simulated conditions in VLADIMIR. The analysis included investigation of the participants' own assessment of the realism of the VLADIMIR routes they had chosen, a comparison of models based on the real life routes with models based on VLADIMIR routes and a statistical comparison of the two sets of routes.

Bonsall et al (1997) concluded that, a well designed simulator with a realistic and comprehensive network is able to replicate real life route choices with a very high degree of detail and accuracy.

2.4.5 Driver Behavior Modeling

Koing et al (1994) developed a driver behaviour model which responds to information and traffic messages. This model consists of four submodels, which describe the drivers' driving behaviour, preferences, reactions to incoming messages and the knowledge of the network.

Driving behaviour comprises all levels of aggressiveness and non-aggressiveness characterised by the driven speed, the acceptance of braking distance, the use of lanes on motorways, and the frequency of overtaking. The driver's preference are an important aspect for the driver modelling; the driver might prefer particular street types such as motorways, federal roads or ordinary roads in non-urban areas or avoid certain sections, roads, regions, or areas with speed limits. In addition, the reactions of the driver to incoming messages are significant. These reactions depend on the quality of the messages, and the route recommendations. The driver's local knowledge is also important for his/her possible reaction to traffic messages. In urban regions, the driver might know only some parts of the city or the whole place. This can influence his/her choice of a certain route and his/her driving behaviour to a high degree.

2.4.6 Concluding Remarks

The following conclusions can be summarised from the review of various methods to investigate drivers' route choice under the influence of real-time information.

1. Using field surveys yields results suitable for a limited set of messages in a limited range of circumstances. Also, it is relatively expensive and causes traffic disruption.

2. Route choice simulators are able to produce quantified estimates of drivers' response to a wide range of different VMS messages.

3. The route choice simulators are an ideal tool for understanding drivers route choice in the presence information but, they must clearly be used with considerable care and not applied to problems to which they are not suited.

4. The use of route choice simulators is very expensive because it is required to build a realistic replica of road networks.

5. The attraction of the stated preference approach stem from its ability to control the choice context and the independent variables that will enter the route choice model, and its ability to design the questions to relate to drivers journey rather than a hypothetical journey.

6. The stated preference survey is cheaper than field surveys and route choice simulators.

7. The main shortcoming of the stated preference approach is related to the fact that individuals are not committed to behave in real life in accordance with their SP responses.

2.4.7 Factors Affecting Route Choice Behavior in the Presence of VMS Information

Regardless of the survey type, it was found from the reviewed papers that the main factors that may have a potential effect on the drivers' route choice behaviour in the presence of displayed information by VMS's are:

- **VMS content:** the different causes and duration of delay.
- **The relative attractiveness of routes:** measured by the difference in travel time between the usual and alternative routes under normal conditions.
- **Visible queue**: the presence of visible queues on the usual and alternative routes.
- **Familiarity with the network**: drivers' familiarity with the network surrounding the usual route.
- **Existence of later points for diversion**: existence of next potential diversion points.
- **Experience with VMS**: prior experience of drivers with VMS.
- **Driver attributes**: age and gender.
- **Trip purpose**: including commuting, and others.

2.5 NETWORK IMPACTS OF VMS INFORMATION

One objective of this research is to demonstrate that VMS information can be used to develop more efficient incident management plans. This requires an evaluation and assessment of the network impacts of various VMS messages in order to select the most beneficial solution. This section presents a review of some simulation/assignment models that can be used for this purpose.

2.5.1 Traffic Assignment Models

The University of Leeds' Institute for Transport Studies developed SATURN, a traffic assignment model, for the evaluation of limited area traffic management schemes. It incorporates two phases: the simulation and the assignment phases. The simulation phase determines intersection delays and flow-delay relationship based on a given traffic pattern. Then, this delay is passed to the assignment phase which selects the routes with minimum time/cost through the network for each element in the O-D trip matrix considering the relationships between travel time and flows. Accordingly, the resulting traffic pattern determines a new set of intersection delays. These iterations are repeated until the flow of two consecutive simulations are within a user-defined convergence criterion. SATURN models signalized, priority, and roundabout intersections separately. SATURN assumes that the traffic is represented by a fixed O-D trip matrix. Thus, it is suitable for the analysis of "movement-based" control systems such as one way streets, signalized intersections and bus-only lanes (Hall et al 1980, Van Vliet 1982, James & Davies 1986).

The UK Transport and Road Research Laboratory developed CONTRAM, a traffic assignment model, to use in the design of traffic management schemes in urban areas. It is a capacity restrained model which takes account of the variation of traffic through time and the build up and decay of congestion at intersections during peak periods. Traffic demands are defined as O-D flows for each given time interval. The vehicles for each O-D movement are treated in groups called packets, which are assigned to the network at a uniform rate for each time interval. Each packet travels along its path to its destination. For each link of the packet trip, flows and travel times are updated, and a record of the links used and the arrival time at that link is stored for each packet. CONTRAM uses an iterative process to assign packets to their minimum travel time routes through a network considering the delay at each intersection at the time the packet reaches that intersection (Leonard et al 1982, 1989).

Taylor (1990) presented CONTRAM 5, which includes many improvements to the CONTRAM model. These improvements include: modelling of the effect of signal coordination, estimation of the geometric delay at intersections, speed/flow relationship for links minimum perceived cost assignment, an improved fuel consumption model, variable saturation flows and capacities for individual time intervals.

RGCONTRAM, which is a development of CONTRAM, was developed at Southampton University to model Dynamic Route Guidance (DRG) systems including variable message signs. RGCONTRAM separates the routing of guided vehicles and unguided vehicles, and takes into account drivers' familiarity with the network. Also, it models incidents and the different categories of drivers. As guided vehicles move through the network, they transmit their journey times to the DRG center for use in updating the historic journey time profile for each link. Then, a journey time forecasting is carried out for up to a one-hour time horizon. Accordingly, the routes which have a minimum time/cost are determined and transmitted back to vehicles considering the forecast journey time on each link the vehicle reaches. RGCONTRAM can operate in either of two forms: as an equilibrium assignment model, which produces a user optimum solution subject to the DRG system characteristics, or as a "once-through" non-equilibrium simulation, to study the DRG and network performance during incidents where the dynamic nature makes the use of an equilibrium approach inappropriate (McDonald et al 1995).

Chatterjee et al (1998, 2000) and Hounsell et al (1998) used RGCONTRAM to assess the impacts of VMS on Network performance in London through the CLEOPATRA project which is a telematics project in the European Commission's Fourth Framework programme. The network performance measures provided by the model included link flows, queuing and trip times, distance traveled and environmental parameters such as fuel consumption.

The modeling process used to get the impacts of VMS is carried out in three steps. First, the CONTRAM assignment model is run to generate the used routes in normal conditions. Then, RGCONTRAM is run twice to model the effect of the incident without and with VMS. Without the VMS information, traffic is assumed to stay on CONTRAM routes, while traffic may divert from these routes depending on the VMS information displayed to the drivers. The assumption used in RGCONTRAM in the presence of VMS information is that all the drivers passing VMS and intending to drive through the incident affected area divert to an alternative if a better option, in terms of travel time, exists at the time. This study did not incorporate a realistic model for the effect of VMS information on drivers' route choice behaviour into RGCONTRAM (Hounsell et al 1998, Chatterjee et al 1998, 2000).

McDonald and Richards (1996), and McDonald et al (1998) used RGCONTRAM to evaluate the impacts of VMS, in the presence of incidents, on network performance in Southampton through the ROMANCE project which is a partner in the European project EUROSCOPE. The model has been used to get the optimum diversion rates in different incident situations and to assist in selecting the appropriate VMS Plan.

The modeling approach used to evaluate the VMS impacts consisted of two parts. First, the CONTRAM assignment model is run to simulates road network in normal conditions and obtain the base traffic assignment. Then, the obtained results are fed into RGCONTRAM to simulate the impacts of VMS information. Accordingly, the potential impacts of VMS information can be explored for a range of situations and different traffic management strategies can be developed and assessed. The assumptions used in RGCONTRAM are: firstly, all drivers remain in their usual route with no diversion when the VMS is not in operation; secondly, the proportion of diverted drivers due to the VMS is randomly chosen from those passing the VMS and the incident link in normal conditions; thirdly, the diverted drivers are reassigned to a user-specified alternative route and then reassigned to their destinations using imperfect knowledge of the network conditions; finally, the drivers passing the VMS who do not divert remain on their usual route (McDonald & Richards 1996, McDonald et al 1998).

2.5.2 Traffic Simulation Models

Two types of models are commonly used in urban traffic simulation. These types are macroscopic and microscopic simulation models. Macroscopic models group vehicles into flow and apply the flow relationships to determine successive traffic state. On the other hand, microscopic models calculate the state of the system on the basis of individual drivers and vehicles and their interactions. Macroscopic models may not be adequate to evaluate the impacts of using the VMS information on network performance since they are based on a coarse representation of traffic flow. On the other hand, microscopic models are more suitable for evaluation of the impacts of VMS information, since they provide accurate representation of the actual traffic conditions, but they require very complex computer programming and involve great storage requirements and computing time. This section focuses on reviewing the relevant microscopic simulation models.

Rathi and Santiago (1990) developed a modified version of the TRAF-NETSIM network simulation model. This model describes the operational performance of vehicles travelling over a network of urban streets. The vehicles are represented individually and their operational performance is determined every second. The vehicles entering the network are moved each second according to the car-following logic while responding to traffic-control devices, pedestrian activity, transit operations, performance of adjacent vehicles, and other conditions that influence driver behaviour. Furthermore, each vehicle is identified by a category, a type, and some driver behavioural characteristics.

TRAF-NETSIM has the capability to simulate the effects of traffic control ranging from a single stop sign controlled intersection to dynamic, real-time control systems. The model simulates bus operations, the effects of blockers and parkers, spillback, overflowing, turn pockets, and other elements of traffic operations on surface street networks.

The output of the model includes a variety of measures of effectiveness (speed, volume, density, delay, spillback, queuing, turn movements) and estimates of fuel consumption and emissions on each link of the network, groups of links, and the entire network over user-specified time intervals.

The modified version of TRAF-NETSIM model contains incorporating four new features in the model. These features include: actuated signal logic, to allow the simulation of traffic actuated signal control; and identical traffic streams, to allow the user to perform a series of runs with traffic streams that exhibit identical routing patterns and driver-vehicle characteristics. Thus, the user can test different control strategies with the assurance that each strategy is applied to the same traffic stream and that the change in system's response is due primarily to change in the control variables, not to random variation. Also, the new features of TRAF-NETSIM include: signal transition algorithms, to minimise the disruption on traffic operations when the signal settings transform from one fixed-time pattern to the next; and conditional turning movement feature, to provide the capability of restricting vehicles from making a series of unrealistic turns (Rathi & Santiago 1990).

In addition to the four enhancements described above, several modifications have been made to the TRAF-NETSIM logic. These modifications are: (a) vehicle generation, to allow better vehicle generation under congested conditions; (b) over flowing turn pockets, to assure that the vehicles will stop and join a queue when the turn pocket are full; and (c) lane change decisions, to allow the vehicles in the middle of a queue to seek a lane change in order to improve their position in the queue.

The TRAF-NETSIM model was found to be unable to simulate traffic flow when exceeds the capacity and unable to simulate incidents and the related drivers behaviour. Also, the model can not simulate the actual traffic flow within intersections.

Rathi and Venigalla (1993) proposed two variance reduction techniques to improve the efficiency and reliability of simulation experiments with TRAF-NETSIM simulation model. The two variance reduction techniques are antithetic variates and common random numbers. These techniques reduce the variance of simulation output by replacing the original sampling procedure by a new procedure that yields the same parameter estimate but with a smaller variance. Thus the users can obtain greater statistical accuracy for the same number of simulation runs.

Hidas and Behbahanizadeh (1995) developed a network simulation model called SITRAS. The model was designed as an analysis tool for advanced traffic management technologies, such as dynamic route guidance systems, congestion and incident management systems, various forms of electronic road pricing and high occupancy vehicle systems.

SITRAS model is a microscopic time-interval-update simulation model in which vehicles are generated and moved through the network on an individual basis. The input data required by the model consists of traffic data, including both quantitative and qualitative information about vehicles and drivers; network data, links and nodes; and traffic control data. The main modules of the model include vehicle generation, vehicle progression, based on car following and lane changing theory; and route selection, based on individual driver characteristics. Vehicle generation uses a random process from a negative exponential distribution, according to the given flow rate, demand distribution of trip destinations and vehicle composition. The module can handle variable flow rates in order to study the dynamic effects of increasing or decreasing demand patterns. The model allows the simulation of unguided and guided vehicles. For unguided vehicles, drivers' imperfect knowledge of the prevailing network conditions was modelled according to Burrell's simulation method, in which drivers perceived minimum cost of the route that they follow includes an error term distributed uniformly around the prevailing true cost, with a spread factor chosen by the user. All guided vehicles were assumed to follow the given route advice based on the prevailing minimum cost routes.

The route choice method applied in SITRAS model for guided vehicles is unrealistic because not all drivers would comply with all advice and the level of compliance is to be a function of several factors such as the quality and clarity of the advice and the drivers' behaviour.

Hidas and Behbahanizadeh (1998) presented new developments and applications of the SITRAS model. The first development includes a car following model developed specifically for the microscopic simulation of urban interrupted traffic flow conditions. The model is based on a desired spacing criterion which is assumed to be a linear function of the speed. The model eliminates the problem associated with the apparent reaction time inherent in previous models. The second development includes new lane changing algorithms which can be used under congested and incident conditions. The previous rules describing drivers lane changing manoeuvre assume that the lane change takes place without forcing other vehicles in the destination lane to slow down or stop and this is not true in an incident situation, but vehicles have to force their way into the destination lane. The third development includes modelling of the impacts of incidents on vehicles in adjacent lanes, since the incidents not only block the lanes which they occupy but also have a strong capacity reduction effect on the adjacent lanes due to speed reduction of other drivers who are temporarily distracted by the incident.

Hidas and Behbahanizadeh (1998) presented new experiments to investigate the effectiveness of dynamic route guidance systems as an incident management tool, and quantified the effects of incidents of various lengths and severity on a freeway section. The experiments demonstrated the usefulness of a computer simulation model as an evaluation tool for Intelligent Transport Systems applications.

Yang and Koutsopoulos (1996) presented a microscopic traffic simulation model, MITSIM, for modelling traffic networks with advanced traffic control, route guidance and surveillance systems. This model was designed to test and evaluate designs of advanced traffic management systems and advanced traveller information systems. MITSIM represents networks in detail and simulates vehicle movements using car following, lane changing, and traffic signals responding logic. MITSIM contains a probabilistic route choice model to simulate the drivers' route choice behaviour in the presence of traffic information provided by route guidance systems.

MITSIM represents road networks by nodes, links, segments, and lanes. The surveillance system in the model consists of various detectors that collect data on traffic flows in the network such as traffic volume, speed, and occupancy. MITSIM has the ability to simulate a wide range of traffic control and route guidance devices such as intersection controls, ramp controls, variable message signs and electronic route guidance devices. MITSIM accepts the time dependent origin-destination, OD, tables as input (Yang & Koutsopoulos 1996).

Barcelo et al (1998) presented a microscopic simulation model for urban networks called AIMSUN2. This model consists of two main parts. The first part contains an accurate description of the road network geometry including traffic facilities as traffic lights, traffic detectors, and Variable Message Sign Panels.The second part is the detailed modelling of traffic behaviour which reproduces the dynamics of each individual vehicle, distinguishing between different types of vehicles, offering the possibility of taking into account behavioural aspects of drivers. AIMSUN2 represents road networks by nodes, links, and lanes. Each vehicle is modelled according to several driver behaviour models as car following, lane changing, gap acceptance. AIMSUN2 can model incidents and conflicting manoeuvres.

The input data required for AIMSUN2 consists of three types: network description, traffic control plans and traffic conditions. The network description contains information about the geometry of the network, turning movements, layout of links and junctions and location of detectors along the network. The traffic control plans consist of the description of stages and their duration for signal controlled junctions, the priority definition for unsignalized junctions and any required ramp-metering information. The most important data for the model is the traffic volumes at the input sections, the turning proportions at junctions and the initial state of the network. The output from AIMSUN2 provides a continuously animated graphical representation of the traffic network performance; a print out of flows, speeds, journey times, delays, and stops; and the data gathered by the simulated detectors which includes traffic counts, occupancy, speeds, and queue lengths (Barcelo et al 1998).

Paramics which is a suite of software tools for microscopic traffic simulation was developed by Quadstone Limited (1998). Individual vehicles were modelled in detail for the duration of their entire trip, providing the accurate and dynamic traffic flow information necessary for the analysis of congested road networks. Paramics models a system where the OD matrix definition generates trips from zone to zone. For each trip, a unique vehicle is created which carries a conceptual driver and passengers. In addition, the vehicle carries a set of parameters, about 75, that define the physical and behavioural characteristics of that driver-vehicle unit.

Paramics includes a sophisticated microscopic car-following, gap acceptance, and lane changing model, for roads of up to 32 lanes in width. Also, dynamic and intelligent routing were modelled.

Route choice in Paramics is determined by the minimisation of generalised cost function incorporating time, distance and other cost elements. Multiple routing between O-D pairs is simulated through a variation of a Burrell type assignment, whereby each vehicle has its own perception of the cost of a route and subsequently determines its own route. Given that each and every vehicle has its own perception of a route's cost, the assignment methodology within Paramics could be described as multiple user class stochastic assignment at the most disaggregated level.

Paramics is not an equilibrium model and does not seek a pre-determined solution to the traffic assignment problem. This is illustrated by the fact that every simulated vehicle in Paramics model will take a different time to reach its destination from every other vehicle making the same O-D journey. This is true even if it uses exactly the same route as another vehicle because, a vehicle's simulated journey time is dependent upon network conditions at the time the vehicle was undertaking its journey and the individual characteristics of the vehicle and its driver.

Paramics can simulate the traffic impacts of signals, ramp meters, loop detectors linked to variable message signs, VMS and CMS signing strategies, in-vehicle network state display devices, and in-vehicle message advising of network problems and re-routing suggestions.

Algers et al (1997) introduced a review of the existing micro-simulation models as part of the SMARTEST Project. The features of these models are shown in Table 2.1 and Table 2.2.

Table 2.1 Transport Telematics Functions Studied (Algers et al 1997)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
AIMSUN 2	X	X		X		X	X	X		X	X			X							X
ANATOLL															X						
AUTOBAHN	X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	X
CASIMIR		X																			X
CORSIM	X	X	X	X	X	X															
DRACULA	X	X	X												X						X
FLEXSYT II	X	X	X	X	X	X	X							X					X		X
FREEVU																				X	X
FRESIM				X	X	X															X
HUTSIM	X	X	X	X				X		X				X		X		X	X	X	X
INTEGRATION	X	X	X	X	X	X		X		X	X		X	X	X					X	X
MELROSE	X	X		X	X		X		X	X				X	X	X	X	X		X	X
MICROSIM		X		X						X	X										
MICSTRAN	X	X	X	X			X			X	X	X			X						X
MITSIM	X	X		X	X	X		X		X	X			X						X	X
MIXIC					X											X	X	X			
NEMIS	X	X	X			X	X	X		X	X					X				X	X
NETSIM	X	X	X			X															X
PADSIM	X	X					X				X					X					X
PARAMICS	X	X		X	X	X	X	X	X	X	X			X	X		X			X	X
PHAROS	X																				
PLANSIM-T	X	X	X	X			X	X	X	X	X	X			X		X			X	
SHIVA																X	X	X			X
SIGSIM	X	X	X	X	X	X							X			X		X		X	X
SIMDAC																X					
SIMNET	X	X	X	X		X		X		X	X	X				X					X
SISTM				X	X			X		X											X
SITRA-B+	X	X	X			X				X	X	X								X	X
SITRAS	X	X				X				X	X										X
THOREAU	X	X		X				X		X	X									X	X
VISSIM	X	X	X	X	X								X						X	X	X

1 Co-ordinated traffic signals
2 Adaptive traffic signals
3 Priority to public transport vehicles
4 Ramp metering
5 Motorway flow control
6 Incident management
7 Zone access control
8 Variable message signs
9 Regional traffic information
10 Static route guidance
11 Dynamic route guidance
12 Parking guidance
13 Public transport information
14 Automatic debiting and toll plazas
15 Congestion pricing
16 Adaptive cruise control
17 Automated highway system
18 Autonomous vehicles
19 Support for pedestrians and cyclists
20 Probe vehicles
21 Vehicle detectors

Table 2.2 Objects and Phenomena Modelled (Algers et al 1997)

	1	2	3	4	5	6	7	8	9	10	11	12	13
AIMSUN 2								X	X		X	X	X
ANATOLL											X		
AUTOBAHN	X			X	X			X		X	X	X	X
CASIMIR													
CORSIM		X	X		X		X	X	X		X	X	X
DRACULA	X				X			X	X		X	X	X
FLEXSYT II					X	X	X	X	X	X	X	X	X
FREEVU				X							X	X	
FRESIM					X			X	X		X	X	
HUTSIM						X	X	X	X	X	X	X	X
INTEGRATION					X			X	X	X	X	X	X
MELROSE			X		X		X				X	X	
MICROSIM											X		
MICSTRAN	X		X		X		X		X		X	X	
MITSIM	X		X	X	X			X		X	X	X	X
MIXIC	X			X						X		X	
NEMIS				X	X			X	X	X	X		X
NETSIM		X	X		X		X	X	X		X	X	
PADSIM			X								X		X
PARAMICS	X	X			X			X	X	X	X	X	X
PHAROS											X	X	X
PLANSIM-T					X				X		X	X	X
SHIVA												X	
SIGSIM			X		X	X		X	X		X	X	
SIMDAC								X		X			
SIMNET			X	X				X	X	X	X		X
SISTM	X				X			X			X	X	
SITRA-B+		X	X		X			X	X		X	X	X
SITRAS					X			X			X	X	
THOREAU	X		X				X	X		X	X	X	X
VISSIM			X	X	X		X	X	X	X	X	X	X

1 Weather conditions
2 Search for a parking space
3 Parked vehicles
4 Elaborate engine model
5 Commercial vehicles
6 Bicycles / motorbikes
7 Pedestrians
8 Incidents
9 Public transports
10 Traffic calming measures
11 Queue spill back
12 Weaving
13 Roundabouts

2.6 CLOSING REMARKS

Based on the literature review presented in this chapter, the following conclusions were drawn.

2.6.1 Investigating Drivers' Route Choice Behaviour in Presence of VMS Information

a- Several approaches, which have been utilised to investigate drivers' route choice behaviour when affected by VMS information, were reviewed.

b- No single approach was proved to be perfect since all of them have disadvantages as well as advantages.

c- The Stated Preference approach was selected since its advantages are more appropriate for this study. These advantages are:

- the ability of the SP approach to control the choice context and the independent variables that will enter the route choice model,
- the ability of the SP approach to design questions related to drivers journey rather than a hypothetical journey, and
- The SP approach is cheaper than the other survey approaches.

2.6.2 Evaluation of Network Impacts of VMS Information

a- Several models which can be used to evaluate VMS impacts on network performance, were reviewed.

b- The need is for a realistic simulation for the effect of VMS information on the surrounded network. That can be achieved by incorporating a realistic route choice model for the effect of VMS information, based on collected data, into the simulation model.

c- The SITRAS microscopic simulation model was selected for this study for the following reasons:

__The following section to be added after section 2.6__

2.7 OVERVIEW OF THE RESEARCH APPROACH

To achieve the research objectives, the following tasks have been carried out:

- A survey was conducted to investigate drivers' route choice behaviour in the presence of different VMS information for any trip in the Sydney Metropolitan Region. The survey utilised the stated preference technique in which each person had to state how he/she would behave in response to different scenarios. The VMS messages which were shown to respondents contain incident type: ACCIDENT, ROADWORKS or CONGESTION; and incident severity: qualitative delay (DELAYS or LONG DELAY), or quantitative delay in minutes. The collected data was analysed to reveal the sample characteristics and to explore the effect of the survey parameters on the diversion rate.

- A general route choice model was developed which can be used to predict the diversion probability in response to various VMS message contents. The model development included four main steps: model formulation, model building, testing of the model fit, and model validation. The form of the logistic models was chosen for the developed model. Building the model was performed through four stages: (a) selection of the variables and verification of the importance of each independent variable included in the model, (b) checking collinearity among the independent variables and suggesting modifications if needed, (c) checking the linearity in the logit and suggesting modifications if required, and (d) checking if interaction terms need to be included among the independent variables in the model.

- A parametric study was performed to analyse the effect of the different explanatory variables on the probability of diversion.

- The developed VMS model was implemented and verified in SITRAS simulation model to enable the analysis of VMS impacts on network performance.

- An assessment of the benefits of using VMS as an incident management tool was performed through the M2 Hills Motorway case study. Different Incident Management (IM) Plans were introduced and the optimum plan, which gives the maximum benefits of using VMS, was recommended. Also, the effect of increasing the flow rate of the incident link on the effectiveness of VMS, for the recommended incident management plan, was investigated.

- SITRAS simulates the details of traffic flow on urban road networks with focus on simulating congested conditions
- SITRAS simulates incidents of various severity and duration which enable the model to be utilized for evaluation of incident management strategies.
- It simulates guided as well as unguided vehicles
- It has been developed at the UNSW which make it available for use and for adding a realistic route choice model in the presence of VMS into.
- Therefore, the proposed route choice model, which investigates the effect of VMS information on the drivers' route choice behavior, can be incorporated into SITRAS to evaluate the impacts of using VMS information on network performance.

CHAPTER 3
DATA COLLECTION AND ANALYSIS

3.1 DATA COLLECTION

A survey was designed to investigate drivers' route choice behaviour in the presence of different VMS information. This survey was conducted by collecting data on drivers having at least one alternative route in addition to their usual route. The survey utilised the stated preference technique in which each driver has to state how he/she would behave in response to different scenarios.

3.1.1 Survey Design

3.1.1.1 Data Collection Technique

The data was collected using the personal interview survey. The personal interview survey is one in which an interviewer poses a series of questions to a volunteer respondent and records the answers on a questionnaire. This type of survey was chosen for the following reasons:

1. The presence of an interviewer means that explanations can be given regarding the meaning of questions or the methods in which answers are to be given.
2. The survey can be carried out over a short period of time.
3. The interviewer can make sure that the full set of questions is completed.
4. A high response rate may be ensured.

3.1.1.2 Trip Selection

The selection of the trip to be considered in the interview was an important issue in the survey design. All of the overseas studies used one or a few pre-selected trips in their surveys. While this type of survey may provide more accurate data pertaining

The following text to be added at the end of the first bullet point in section 3.1.1.3

Incident types include ACCIDENT, ROADWORKS, and CONGESTION; and incident severity includes LONG DELAY, DELAYS, and minutes of delay.

to the conditions of the selected trip, it has several significant disadvantages. First, it makes it far more difficult to find respondents having experience with the pre-selected route. Second and more importantly, the results are not well suited for the development of a general model. In particular, they provide very limited information on the relationship between the trip time and the 'Extra Travel Time', ETT (ie. the difference between the usual and alternative trip time) which is a crucial factor identified by most previous studies.

For these reasons, the survey was designed to be based on any car trip in the Sydney Metropolitan Area, which has at least one alternative route. This survey method was selected because it can provide information on a more continuous range of trip times. Thus, it enables the development of a prediction model of the diversion probability which can generally be applied anywhere in Sydney at any location regardless of the trip origin, destination and trip length. From a survey organisational viewpoint, this method also made it easier to find the required number of respondents. A potential weakness of the method is that the variance of the answers collected from a wide range of trips included in the analysis may be larger than in the case of one specific trip between fixed origin and destination. Therefore, the model developed from these results may be less accurate. Nevertheless, this data collection method is considered more appropriate for the objectives of this study.

3.1.1.3 Survey Parameters

To achieve the survey objective, data must be collected on all parameters which are considered to have a potential effect on the drivers' route choice behaviour in presence of VMS information. These parameters are:

- **VMS content**: the different types and severity of incident.
- **The relative attractiveness of routes**: measured by the difference in travel time between the alternative and usual routes under normal conditions.
- **The trip length**: the trip travel time between the first diversion point immediately downstream of the VMS location and the trip destination under normal conditions (on the usual route).

- **Visible queue**: the presence of visible queues.

- **Familiarity with the network**: drivers' familiarity with the network surrounding the usual route.

- **Existence of later points for diversion**: existence of next potential diversion points.

- **Willingness of diversion at next potential diversion points**: this parameter has not been tested or considered before in any of the previous studies. But we believe that it may have a significant effect on the probability of diversion.

- **Experience with VMS**: prior experience of drivers with VMS and their assessment of its quality.

- **Driver attributes**: age and gender.

- **Trip purpose**: commuting, shopping, entertainment, and others.

3.1.1.4 Questionnaire Design

The questionnaire was designed to investigate the impact of the survey parameters on the route choice behaviour in presence of VMS information. Each questionnaire consists of three parts, 16 question, as follows and as shown in Appendix A.

- Trip Characteristics: trip purpose, origin and destination, and names of the usual and potential alternative routes for this trip, questions 1 to 5.

- Four VMS scenarios: this is the main part of the questionnaire in which a number of hypothetical VMS messages, 4, should be displayed to each respondent and he/she has to state which route he/she would select in the given situation, questions 6 to 10. In this part, the travel time between the first diversion point immediately downstream of the VMS location and the drivers' destination should also be recorded for both usual and alternative routes.

The following section to be added after section 3.1.1.4

3.1.1.5 The experimental design of the stated preference exercise

The factors which were considered in the design of the SP exercise are incident types and severity. Incident types include ACCIDENT, ROADWORKS, and CONGESTION; and incident severity includes LONG DELAY, DELAYS, and minutes of delay. The profiles, which were presented to each respondent, were selected according to his/her trip travel time on the usual route as shown in the table in page 169, and to the required number of profiles to be used by each interviewer. This number was estimated to obtain equal number of responses for all the VMS signs used.

- Respondent characteristics: willingness to divert at subsequent diversion points, previous experience and assessment of VMS, familiarity with the network, age and gender, questions 11 to 16.

3.1.1.5 Sample Size

The selection of a proper sample size is an important pre-requisite to any survey. The essence of sample size calculations is one of trade-offs. Too large sample means that the survey will be too costly for its objective and the required degree of precision. Too small sample will mean that results will be subject to a large degree of variability and this may mean that decision can not reliably be based on the survey results. In such situations, the entire survey effort may have been wasted. Somewhere between these two extremes there exist a sample size which is most cost-effective for the survey objects (Richardson et al. 1995).

Using the simple random sampling method and based on the central limit theorem, the required sample size for estimation of proportion *p* can be obtained as follows (Richardson et al. 1995):

$$n = \frac{p(1-p)}{s.e.(p)^2}$$

where,

s.e.(p) = the acceptable standard error and is calculated as follows:

s.e.(p) = Sampling error / Z

Using sampling error 5% & 10%, the sample size for different proportions p was estimated and presented in Table 3.1.

Table 3.1 shows that, if the expected proportion of diverted drivers as a result of a specific VMS message equals 10%, then the required sample size equals 24 with 90% confidence limit and 138 with 95% confidence limit. Also, at the same confidence limit, the required sample size increases as the expected proportion of diverted drivers increases. Accordingly, at proportion of 50%, the required sample size is 67 and 384 for 90% and 95% confidence limit respectively.

Table 3.1 The Required Sample Size for Sampling Error 5, 10%

The Diverted Proportion	Sample Size	
	Level of Confidence 95%*	Level of Confidence 90%**
10%	138	24
20%	245	43
30%	322	56
40%	368	64
50%	384	67

* At Level of Confidence 95%*, Z=1.96

** At Level of Confidence 90%*, Z=1.64

Each questionnaire/interview contains four VMS messages and the total number of VMS messages included in the survey is 18. Thus, the required number of questionnaires/interviews is equal to the sample size obtained from the above table multiplied by 18/4.

The required number of questionnaire/interview for a confidence limit 90%, which is accepted at this survey, is calculated as follows:

Number of Questionnaires = 67 *18/4 ≅ 310

By adding 10% to account for possible errors found in the collected questionnaires:

The Required Number of Questionnaires = 310 *1.10 ≅ 345

3.1.2 Survey Administration

3.1.2.1 Interviewer Selection and Training

The interviewers were selected from the University of New South Wales students by advertising at different notice boards. A few students from other universities were also included.

A training session was conducted to the selected interviewers. In this session the objectives of the survey were explained. In addition, the questionnaires content and the main guidelines for selecting the interviewees were discussed. Also, the coding system and data entry processes were explained to the interviewers.

An Interviewer manual was designed and distributed to the interviewers during the training session. This manual includes a detailed explanation of the questionnaire, the required guidelines in choosing the respondents, and the coding and data entry process as shown in Appendix B. Also, a template file of the data entry sheet in Microsoft Excel format was sent to all the interviewers via e-mail.

3.1.2.2 Interviewer Task

The interviewers were responsible for selecting their interviewees according to the guidelines distributed to them at the training session. The interviewees may be friends of the interviewer, some people working with them or/and any other people willing to complete the questionnaires with the interviewer. The main tasks of the interviewer were:

a. Conducting the interviews

b. After each interview:

   - making a valuable assessment of the validity of the recorded answers by noting the interest of the respondent in the survey
   - write any additional information or opinions given by the respondent
   - record any notes observed by the interviewer on the interview
   - doing field editing to ensure that all questions were asked and all answers were recorded

c. Data coding and entry to Excel spreadsheets.

3.1.3 Survey Work

The survey started at the end of September 1999 and finished by the Mid of November 2000. A total number of 405 interviews were conducted on trips longer than 15 minutes, and having at least one alternative route in addition to the usual route, in the Sydney Metropolitan area. A total of 22 interviewers participated in the survey. The total number of questionnaires was divided into two parts. The first part is the prediction sample, 350 questionnaires, which was used to develop a model to predict the effect of VMS information on the drivers' route choice behavior. The second part was used to check the external validity of the prediction model and contains 55 questionnaires.

3.1.3.1 Survey Description

In the survey, respondents were first asked to select a car trip in the Sydney Metropolitan Area which is longer than 15 minutes, and which may have at least one alternative route (beside the "usual route" used by the respondent). Details of these two routes were recorded in the first part of the questionnaire. Then, four hypothetical VMS messages were shown to each respondent, and they had to state which route they would select in the given situation. An example of these questions is shown in Figure 3.1. Finally, respondents were asked some questions related to their personal characteristics. The set of VMS messages used in the survey are shown in Appendix C.

While you are on the way to your destination, imagine that before you approach the intersection at which you could divert to the other route, you see a VMS showing the message below:

Usual Route

Accident ahead

15 Minutes Delay

Which route would you select?

Usual[1]

Alternative[2]

Figure 3.1 An Example of the Key Questions Used in the Interview Survey

The following paragraph to be added at the end of section 3.2.2

In addition, the reality of the responses was verified by comparing the recorded travel time for each trip by our own travel time and verifying the street names which comprises both usual and alternative routes for each respondent.

3.2 DATA PROCESSING

The objective of the data processing is to transform the completed questionnaires into a data form ready for analysis. Data processing was carried out through six steps: initial and final questionnaires editing, data coding, entry, editing, and manipulation.

3.2.1 Initial Questionnaire Editing

The initial questionnaire editing, which is the field editing, was performed by the interviewer to check that there was an answer to each question. This editing task was done after the completion of every interview since the interview was still fresh in the interviewer's mind and he/she could edit the missing information which were given by the respondent and not recorded. Also, the interviewer could return immediately to the respondent to obtain the missing information, which were not asked by the interviewer or given by the respondent.

3.2.2 Final Questionnaire Editing

The final questionnaire editing was carried out after finishing the data collection stage to ensure that the responses of all the questionnaires are completed and to exclude the uncompleted questionnaires. Also, the editing was carried out to detect any errors in the questionnaires.

It was found that all the questionnaires are completed. On the other hand, some errors were detected which have not any noticeable effect. (e.g. Q12: the person who does not have any experience before with the VMS and gives an assessment to the VMS information). These errors were corrected in the data entry file. Also, two questionnaires indicate a travel time of 7 hours, which were excluded from the data set.

3.2.3 Data Coding

Coding is the transformation of data into labelled categories suitable for computer processing. The coding step was carried out by transforming the data into numerical labels. The coding system included two forms. The first is the ratio codes, which were used in representing the quantities of physical attributes such as travel times. The second coding form utilised the nominal property in coding the data. For example, the codes for the selected routes will be "1" for the usual route and "2" for the diverted route.

The questionnaire form on which answers were recorded was also used in the coding process. Codes were typed into boxes printed in the questionnaire against each question as shown in Appendix A.

3.2.3.1 Coding Frame

The coding frame is required to describe the way in which codes are to be allocated to answers and the way for coding each questionnaire. Each questionnaire form was coded using an identification number, the interviewer name, and the date of the interview.

The questionnaire answers were coded as follows:

- The questions which have "Yes/No" answers were coded as "1" for yes and "2" for no
- the questions which have "Usual/Diverted route" answers were coded as "1" for the usual route and "2" for the diverted route
- The "Male/Female" answers were coded as "1" for male and "2" for female
- The answers representing the quantities of physical attributes such as travel times were coded as the numbers which representing actual data (time in minutes)
- In the questions that contain menu items, the answers were coded using the assigned number to it at the questionnaire form.
- The VMS signs were coded as the sign name, e.g., A1, A2
- The missing data were coded as " "

3.2.4 Data Entry

Data entry was carried out using the Microsoft Excel software, which provides many facilities for data entry. Data was entered such as the rows represent data items for each questionnaire, while the columns represent different respondents to the questionnaire. The designed data entry screen is shown in Appendix D.

3.2.5 Data Editing

After the data entry, data editing was carried out for the detection of errors, since there always are errors in the entered data. Data editing was utilised to detect two types of errors: the permissible range error, and consistency checks.

Permissible range errors include errors where the code value is outside the range of permissible codes for that purpose. A check was carried out for the following errors:

- a code other than "1" or "2" for the "Yes/No" questions
- a code different from "1" or "2" for the "Usual/Diverted route" questions
- a code other than the allocated numbers for menu items

A few errors of this type were detected and corrected by referring to the original questionnaire.

Consistency checks reveal logical inconsistencies in the data, which include a respondent who does not have experience before with VMS and gives answer about the VMS reliability or a respondent of less than 16 years old (No one under 16 can hold a driving licence). Some errors of this type were also detected and corrected by referring to the original questionnaire

3.2.6 Data Manipulation

The final step in the data processing, after data editing, was the data manipulation in which data was transformed to a form ready for analysis.

In the main part of the questionnaires, from question 7 to 10, eight responses were recorded from each respondent. Each respondent was asked to indicate which route he/she would select, alternative/usual, in eight scenarios with different VMS contents and visible queues. Thus, data obtained from each respondent was divided into eight cases. Each case has the same data for trip and respondent characteristics, questions 1 to 6 and 11 to 16, but has the responses for only one scenario. The total number of cases for the prediction sample is therefore 2784 (after excluding two questionnaires), and 440 for the validation sample.

3.3 DATA ANALYSIS

3.3.1 Sample Characteristics

Table 3.2 shows the trip and respondent characteristics as revealed in the answers to the questionnaires. As shown in the table, most of the respondents are commuter drivers, 64.7%, and males, 69%. Also, the age of most of the respondents, 90.2%, ranges from 17 to 50 years. About 65% of the respondents are willing to divert at next diversion point while the other respondents are either not willing to divert or have not later diversion points. Less than half of the respondents, 39.9%, drive on the usual route daily, while 35.1% use it few times a week.

Table 3.2 Trip and Respondent Characteristics

(a) Trip Purpose Distribution

Trip Purpose	Observed	%
Commuting	225	64.7
Shopping	36	10.3
Entertainment	44	12.6
Others	43	12.4

(b) Age Distribution

Age	Observed	%
17-35	192	55.2
35-50	122	35.0
>50	34	9.8

(c) Gender Distribution

Gender	Observed	%
Male	240	69.0
Female	108	31.0

(d) Frequency of Willing to Divert at Later Diversion Points

Divert at Later Points/Not	Observed	%
Divert	226	64.9
Not divert/ No later points	122	35.1

(e) Respondent Assessment of the Quality of the Previous Information

Information Quality	Observed	%
No Previous Information	63	18.1
Very Satisfactory	20	5.7
Satisfactory	169	48.6
Uncertain	80	23.0
Very Unsatisfactory	16	4.6

(f) Frequency of Travel on the Usual Route

Travel Frequency	Observed	%
Every day	139	39.9
Few times a week	122	35.1
Once a week	52	14.9
Less	35	10.1

(g) Frequency of Travel on Other Routes

Travel Frequency	Observed	%
Few times a week	60	17.2
Few times a month	119	34.2
Once a month	60	17.2
Less	109	31.4

(h) Trip Time Distribution

Trip Time* (min.)	Observed	%
10 - < 15	25	7.2
15 - 20	57	16.4
20 - 25	71	20.4
25 - 30	50	14.4
30 - 35	54	15.5
35 - 40	11	3.1
40 - 45	31	8.9
45 - 50	17	4.9
50 - 55	10	2.9
55 - 60	2	0.6
60 - 75	20	5.7

* between the first diversion point and the drivers' destination

About 18% of the respondents had no previous experience with VMS at all. Half of the respondents assessed the quality of the previous information, given by VMS, as satisfactory while, half of them were uncertain. The trip times recorded from the survey show a fairly even and continuous distribution: 91% of the trip times ranged from 10 to 50 minutes, while 9% of the trip times were between 50 and 75 minutes.

3.3.2 Analysis of the Effects of Respondent Characteristics and Visible queues

Table 3.3 shows the relationships between various personal characteristics and the proportion of respondents deciding to divert in response to a VMS message. The percent of diversion of the different categories, for each of the trip purpose, age and gender variables, is nearly the same. On the other hand, the percent of diversion changes markedly across the different categories for each of the following variables: visible queue, travel on alternative routes and willingness to divert at later diversion points. Thus, it can be concluded that the variables: visible queue, travel on alternative routes and willingness to divert at later diversion points have an obvious effect on the percent of diversion, while the trip purpose, age and gender variables do not seem to affect the percent of diversion. But, it is not clear whether the variables: travel on usual route and assessment of the quality of previous VMS Information have an effect on the percent of diversion. That is because, the change of percent of diversion across the different categories is not very strong. Notwithstanding these preliminary observations, the significance of each independent variable will be checked through an indepth statistical analysis of the data and described in the model development chapter.

Table 3.3 Respondent Characteristics Analysis

(a) Trip Purpose

Trip Purpose	% Diversion	% Using Usual Route
Commuting	67.5	32.5
Shopping	67	33
Entertainment	65.5	34.5
Others	70	30

(b) Age

Age	% Diversion	% Using Usual Route
17-35	67	33
35-50	68.5	31.5
>50	70	30

(c) Gender

Gender	% Diversion	% Using Usual Route
Male	68	32
Female	67.5	32.5

(d) Willing to Divert at Later Diversion Points

	% Diversion	% Using Usual Route
Divert	72	28
Not divert/ No later points	59	41

(e) Respondent Assessment of the Quality of the Previous VMS Information

Information Quality	% Diversion	% Using Usual Route
No Previous Information	62	38
Very Satisfactory	64	36
Satisfactory	69	31
Uncertain	68	32
Very Unsatisfactory	67	33

(f) Travel on the Usual Route

Travel Frequency	% Diversion	% Using Usual Route
Every day	66	34
Few times a week	68	32
Once a week	70	30
Less	62	38

(g) Travel on Alternative Routes

Travel Frequency	% Diversion	% Using Usual Route
Few times a week	78	22
Few times a month	69	31
Once a month	66	34
Less	60	40

(h) Visible Queues

	% Diversion	% Using Usual Route
No visible queue	72	28
Visible queue on usual route	78	22
Visible queue on alternative route	53	47

3.3.3 Analysis of the Effects of Extra Travel Time, ETT, and Trip Length

To explore the effect of the extra travel time and trip length on the diversion rate, a scatter plot was formed between each of these variables and the diversion rate. Each scatter plot was formed, as described by Hosmer and Lemeshow (1989), by creating intervals of the independent variable, extra travel time or trip length, and calculating the diversion rate of each group as shown in Table 3.4 and Table 3.5. That was done because each respondent chose to divert or not, i.e., the diversion rate of each individual is 100% or 0% which does not reveal the relationship between the diversion rate and the variables. Figure 3.2 shows that the diversion rate decreases, from 75% to 16%, with the increase of ETT from 0 to 40 minute. Also, Figure 3.3 shows that the diversion rate decreases, from 75% to 25%, with the increase of trip length from 10 to 75 minutes. Thus, it can be concluded that both variables: extra travel time and trip length have an obvious effect on the diversion rate.

Table 3.4 Frequency of Extra Travel Time Group by Diversion Rate

ETT Group	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39
% Diversion	75.26	71.13	56.70	59.20	66.67	50.00	28.57	16.67

Table 3.5 Frequency of Trip Length Group by Diversion Rate

Trip Length Group	10-14	15-19	20-24	25-29	30-34	35-39
% Diversion	75.08	70.95	62.48	68.44	66.96	76.92
Trip Length Group	40-44	45-49	50-54	55-59	60-64	70-74
% Diversion	62.35	69.62	68.18	50.00	47.55	25

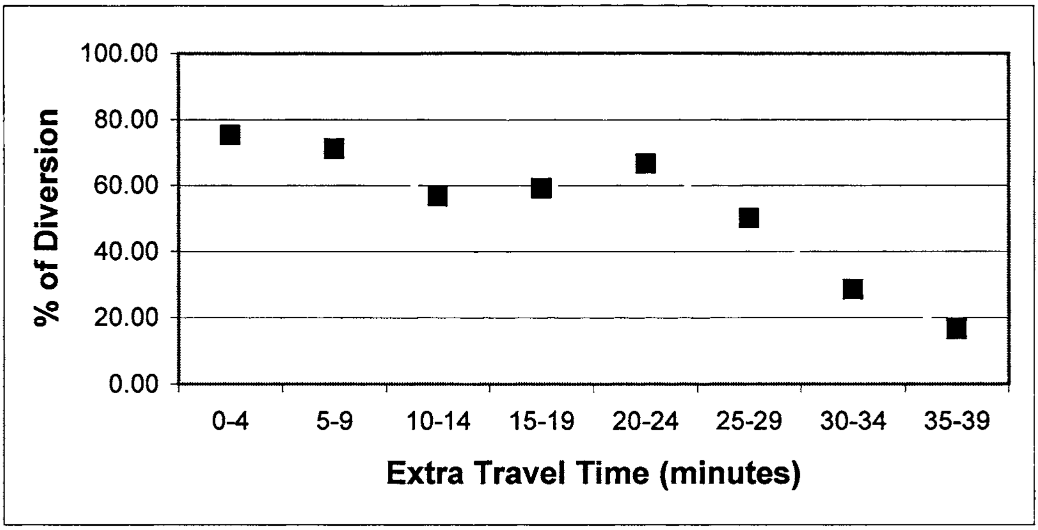

Figure 3.2 Scatter Plot of the Diversion Rate versus Extra Travel Time

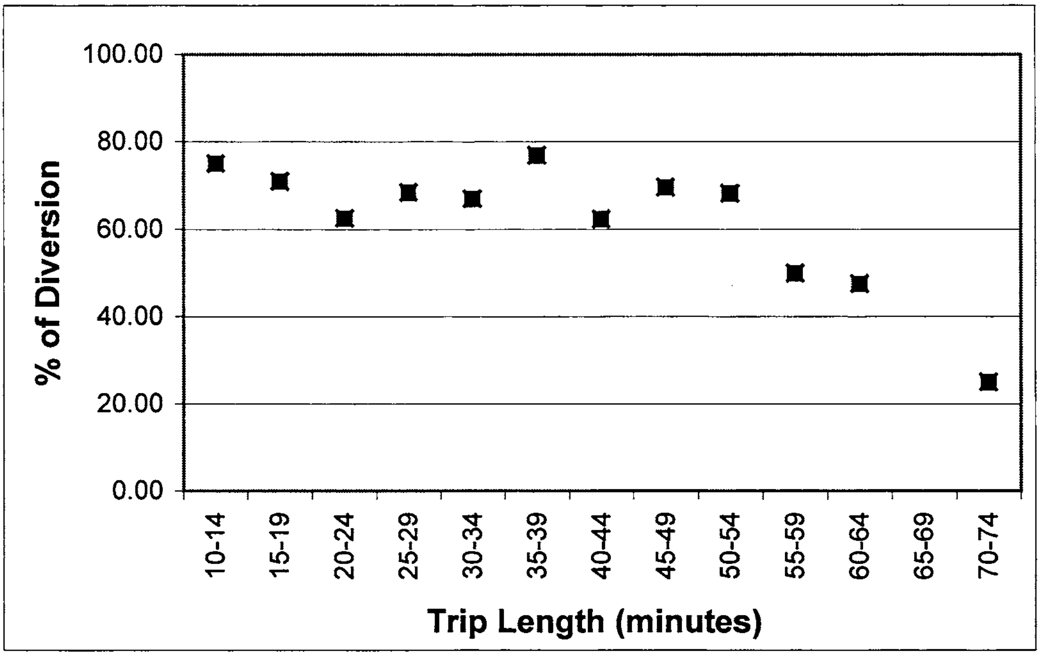

Figure 3.3 Scatter Plot of the Diversion Rate versus Trip Length

3.3.4 Analysis of the Effect of Message Content

Table 3.6 shows that the percent of diversion is nearly constant for the different incident types when the displayed severity is long delay. On the other hand, when the displayed severity is delays, the percent of diversion for accident is larger than for congestion which is lager than for roadworks.

Table 3.6 Percent of Diversion for Different Message Contents

	Long delay	Delays
Accident	71.11	66.21
Congestion	71.17	60.48
Roadworks	71.76	55.56

Figure 3.4 shows that the percent of diversion, when the displayed severity is minutes of delay, for the different incident types is close to each other. In addition, the percent of diversion increases with the increase of displayed delay in minutes for all incident types. Thus, it can be concluded that the displayed delay in minutes has an obvious effect on the diversion rate.

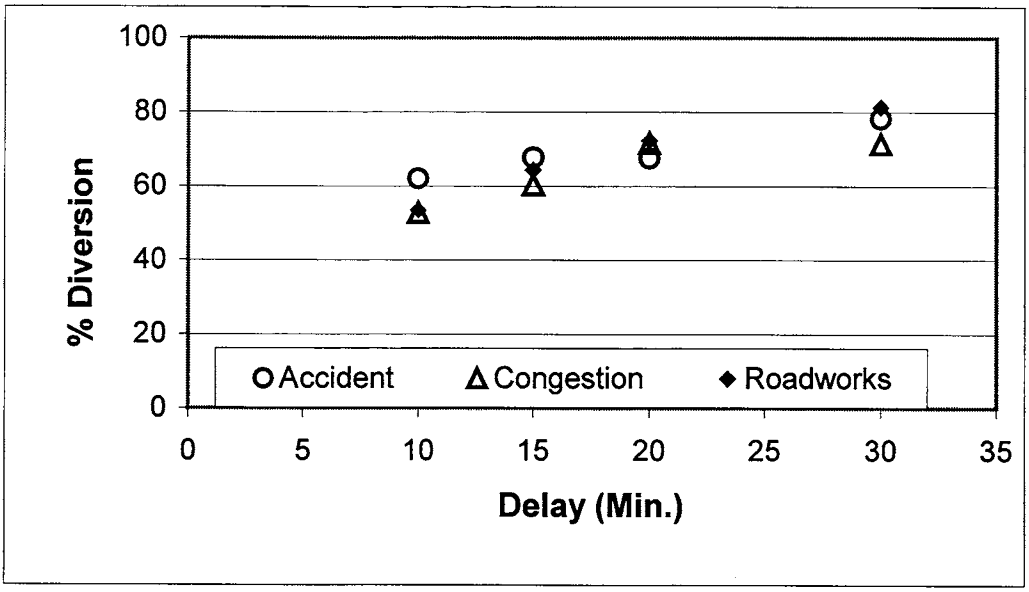

Figure 3.4 Scatter Plot for the Percent of Diversion versus Delay for Different Incident Types

The collected data was utilised for developing a model, as described in the next chapter, which reflects the actual drivers' behaviour when faced with different VMS messages. This model enabled to explore the variables which have a significant effect on the probability of diversion and the relative effect of these variables. Also, the model enables to predict the probability of diversion in response to different VMS information.

CHAPTER 4
MODEL DEVELOPMENT

4.1 MODEL FORMULATION

The model is required to predict the diversion rate in response to the displayed VMS information, based on various driver attributes, including behavioural attributes and route choice decisions. The diversion rate is a continuous value bounded between 0 and 1, while most of the driver attributes have discrete (binary) values.

The logit model is suitable for the required model for the following reasons. First, the logit model predicts the probability of an event, therefore the dependent variable can have any value between 0 and 1. Also, in the calibration process of the logit model, the dependent variable should be in the binary form (0 or 1). Accordingly, the logit model predicts the probability of an event while the model calibration uses binary data on the occurrence of the event .

The form of the binary logit model is as follows (Cramer 1991):

$$\ln\left[\frac{P}{1-P}\right] = \beta_o + \sum \beta_i x_i \qquad (1)$$

where,
P = probability of event occurrence
1-P = probability of event non-occurrence
β_o = constant
β_i = the explanatory variable coefficients
X_i = the explanatory variables

Logit modelling is appropriate with replicated data; that is, data in which there are several cases having the same combinations of levels of predictors (independent variables). More often, this condition is not met when continuous independent variables are considered. Therefore, Logit modelling with continuous predictors is accomplished with individual level data. This technique is referred to as logistic regression (Demaris 1992).

The form of the logistic regression model is as follows (Cramer 1991):

$$P = \frac{e^{\beta_o + \Sigma \beta_i x_i}}{1 + e^{\beta_o + \Sigma \beta_i x_i}} = \frac{1}{1 + e^{-(\beta_o + \Sigma \beta_i x_i)}} \tag{2}$$

$$Q = (1 - P) = \frac{1}{1 + e^{(\beta_o + \Sigma \beta_i x_i)}} \tag{3}$$

where

P = probability of using alternative route (event occurrence)

Q = probability of using usual route (event non-occurrence)

As shown in the above equations of the logit and logistic models, the independent variable coefficients (βs) are the same for both models.

The above form of the logit/logistic models is suitable when the explanatory variables are demographic variables only, such as age and gender. Demographic variables do not vary according to the response category (usual/alternative route) chosen by the individual; rather, they vary only across individuals. On the other hand, the conditional logistic model is used when the explanatory variables are choice specific variables, such as travel time. The choice specific variables take different values depending on the response category even for the same individual (Liao 1994).

The conditional logistic model estimates the effects of a set of choice independent explanatory variables, z_i, on a dependent variable with response categories. The form of the binary model according to the general model given by Liao (1994) is as follows:

$$Prob(y = 1) = \frac{e^{\Sigma \alpha_i z_{1i}}}{e^{\Sigma \alpha_i z_{1i}} + e^{\Sigma \alpha_i z_{2i}}} = \frac{1}{1 + e^{-\Sigma \alpha_i (z_{1i} - z_{2i})}} \tag{4}$$

$$Prob(y = 2) = \frac{e^{\Sigma \alpha_i z_{2i}}}{e^{\Sigma \alpha_i z_{1i}} + e^{\Sigma \alpha_i z_{2i}}} = \frac{1}{1 + e^{-\Sigma \alpha_i (z_{2i} - z_{1i})}} \tag{5}$$

where

Prob(y=1) = probability of the occurrence of event 1 (using alternative route)

Prob(y=2) = 1- prob(y=2)= probability of the occurrence of event 2 (using usual route)

The logit form of the binary version of the conditional logit model can be written according to the general form given by Liao (1994) as follows:

$$\ln\left[\frac{Prob\ (y=1)}{Prob\ (y=2)}\right] = \Sigma \alpha_i (z_{1i} - z_{2i}) \tag{6}$$

The alternative specific constants (ASCs) are typically included in the conditional logistic model by using a set of (1 to the number of response categories-1) dummy variables representing the response categories. The binary model includes only one alternative specific constant. This constant reflects the relative utility of the alternative in which the constant is included -the alternative route- as compared to the one from which it is omitted -the usual route- (Ben-Akiva & Lerman 2000). The binary conditional logistic model with ASCs takes the following form (Liao 1994):

$$Prob(y=1) = \frac{e^{\gamma_1 x_1 + \Sigma \alpha_i z_{1i}}}{e^{\gamma_1 x_1 + \Sigma \alpha_i z_{1i}} + e^{\Sigma \alpha_i z_{2i}}} = \frac{1}{1 + e^{-(\gamma_1 x_1 + \Sigma \alpha_i (z_{1i} - z_{2i}))}} \tag{7}$$

$$Prob(y=2) = \frac{e^{\Sigma \alpha_i z_{2i}}}{e^{\Sigma \alpha_i z_{1i}} + e^{\Sigma \alpha_i z_{2i}}} = \frac{1}{1 + e^{-\Sigma \alpha_i (z_{2i} - z_{1i})}} \tag{8}$$

where,

X_1 = 1

γ_i = the alternative specific constant (ASC)

When the explanatory variables include both choice specific and demographic variables, a mixed model is utilised which combines the conditional logistic model and the logistic model. The form of the binary mixed model according to the general mixed model given by Liao (1994) is as follows:

$$Prob(y=1) = \frac{e^{\Sigma \beta_{1i} x_i + \Sigma \alpha_j z_{1j}}}{e^{\Sigma \beta_{1i} x_i + \Sigma \alpha_j z_{1j}} + e^{\Sigma \beta_{2i} x_i + \Sigma \alpha_j z_{2j}}} \tag{9}$$

$$Prob(y=1) = \frac{1}{1 + e^{-(\Sigma \alpha_j (z_{1j} - z_{2j}) + \Sigma \beta_i x_i + \beta_o)}} \tag{10}$$

Where, both choice-specific explanatory variables z_i, and demographic variables x_i are included in the same model and the subscripts i and j represent the two types of explanatory variables.

The logit form of the mixed model is as follows:

$$\ln\left[\frac{Prob(y=1)}{Prob(y=2)}\right] = \sum \alpha_j \left(z_{1j} - z_{2j}\right) + \sum \beta_i x_i + \beta_o \qquad (11)$$

The selection of the suitable form for the proposed model depends on the parameters used, and that will be discussed in the next section.

4.2 MODEL PARAMETERS

The goal of the proposed model in this study is to predict the diversion rate from the usual route in response to the provided information by VMS's. The factors/parameters that are expected to affect the diversion rate in the presence of the VMS information were selected as the independent variables of the model. These parameters include:

- ***VMS content***: the impact of different types and severity of incident on the route choice behaviour. Incident types include accidents, roadwork, and congestion; and incident severity includes long delay, delays, and minutes of delay.

- ***Travel time difference***: the effect of the difference in travel time between the alternative and usual routes, under normal conditions.

- ***Trip length***: the effect of the trip travel time on the usual route between the first diversion point immediately downstream of the VMS location and the trip destination in normal conditions on the response to VMS information.

- ***Visible queues***: the impact of the presence of visible queues on the response to the VMS information.

- ***Willingness to divert at later points:*** the effect of drivers' willingness to divert at next potential diversion points on the diversion rate.

- ***Familiarity with the network***: the effect of drivers' familiarity with the alternative routes.

- ***Experience with VMS***: the effect of prior experience with VMS on the driver response to VMS information.

- ***Drivers' attributes***: the effect of drivers' attributes, age and gender, on the response to the VMS information.

- ***Trip purpose***: the effect of different trip purposes on the diversion rate.

The demographic variables considered in the study are: driver's age, gender, familiarity with the road network, assessment of the previous VMS information, willingness to divert at the later diversion points, and the trip length and purpose. On the other hand, the choice-specific variable is the travel time which has different values for both usual and alternative routes. Since it is required to explore the effect of the difference in travel time between the alternative and the usual routes (Extra travel time, ETT) on the diversion rate, the ETT variable is used in the model rather than both alternative and usual routes travel times. The ETT variable does not vary according to the response category (usual/alternative route) chosen by the respondent but it varies only across individuals so it can be considered as a demographic variable. Thus, the logistic model shown in equation 10 was chosen as the form of the proposed model in which the ETT variable is used instead of both alternative and usual routes travel times.

4.3 Estimation of the Model Parameters

In the logistic regression, the method used for estimating the coefficients of the independent variables is the maximum likelihood. This method yields coefficient values that maximise the probability of obtaining the observed set of data. The maximum likelihood method is applied by constructing the likelihood function, which expresses the probability of the observed data as a function of the unknown coefficient. The maximum likelihood estimators of the coefficients are the values that maximise the likelihood function. Thus, the resulting coefficient estimators give the best fit for the observed data (Hosmer&Lemeshow 1989). The model parameters have been estimated, and will be presented in section 4.6.

4.4 TESTING THE SIGNIFICANCE OF THE MODEL COEFFICIENTS

Testing the significance of the independent variables in the fitted model is the first request after estimating the variable coefficients. This test aims to determine whether the independent variables of the model are significantly related to the dependent variable. The main measures used in testing the significance are the log likelihood, the model chi-square χ^2, and the Wald tests (Hosmer&Lemeshow 1989).

The log likelihood is the criterion of estimating the independent variable coefficients in the logistic regression model. The log likelihood is usually multiplied by -2. The reason for that is the –2 log likelihood, -2LL, has approximately a chi-square χ^2 distribution. Larger values of –2LL indicate worse prediction of the dependent variable and a good model is one with a small value of –2LL.

The value of –2 log likelihood for the logistic regression model with only the intercept (constant) is similar to the total sum of squares in the linear regression analysis and it is called D_o. Also, the value of –2 log likelihood for the logistic regression model which includes the independent variables as well as the intercept is similar to the error sum of squares in the linear regression analysis and it is called D_M or the deviation χ^2 for the full model. D_M is used in the logistic regression to indicate how poorly the model fits in the presence of all the independent variables.

Another measure in assessing the significance of the independent variables is G_M which is the model chi-square, χ^2. G_M can be obtained by comparing the value of –2LL with and without the independent variables (the likelihood ratio test), ie. G_M is the difference between D_M and D_o. G_M is similar to the regression sum of squares and the multivariate F test in the linear regression. If the model χ^2, G_M, is statistically significant, ie. $p \leq 0.05$, we can reject the null hypothesis that the independent variable coefficients are equal to 0, and accept that the independent variables make better predictions for the dependent variable (Menard 1995).

To assess the significance of each independent variable in the prediction of the dependent variable, the χ^2 for the model containing the independent variable should be compared with the χ^2 for the model without the variable (the likelihood ratio test). The independent variable is significant if the difference in χ^2, for the models with and without the independent variable, is significant, ie. $P \leq 0.05$.

Testing the significance of the independent variables should focus primarily on G_M/the model χ^2 and only secondarily on D_M (Menard 1995).

The above two measures of significance, D_M and the model χ^2, are used to test the overall significance of the independent variables in the model. If the overall effect of the independent variables is not significant based on the previous measures, the Wald test, as well as the likelihood ratio test can be used to assess the significance of each independent variable in the model. The Wald test is obtained by comparing each independent variable coefficient to its standard error and this ratio has a chi-square distribution. Thus, the Wald test can be used to check which of the independent variables in the model may or may not be significant. The independent variables that are not significant, should be removed and a new model should be fit. The new model should be compared to the old one using G_M and –2LL. Also, Hosmer and Lemeshow (1989) suggested that the coefficients of the remaining variables in the new model should be compared in both models. The variables whose coefficients has changed markedly in magnitude indicate that one or more of the excluded variables were significant in the prediction of the dependent variable. If the values of the coefficients are nearly identical in the two models with and without the excluded variables, then the excluded variables do not affect the model. The Wald test can then be applied to the coefficients of the new model. This process should be repeated until the best model is obtained which contains all of the important variables.

Both the Wald and the likelihood ratio tests can be used to test the significance of each independent variable in the model. With large absolute values of the logistic regression coefficients, the estimated standard error may lack precision due to the rounding error, and thus, the Wald test may provide incorrect test for the coefficient's significance. In such cases, the likelihood ratio test should be used instead (Pampel 2000).

4.5 THE EFFECT OF REPEATED RESPONSES

In the main part of the questionnaires, eight responses were recorded from each respondent. Each respondent was asked to indicate which route he/she would select, the alternative or the usual, in eight situations with different VMS contents and visible queues.

In the analysis of the stated preference data, the repeated observations by each respondent are assumed to be independent. But, it is expected that the set of observations related to a given individual is correlated. The effect of this correlation is to overestimate the accuracy with which the variable coefficients can be calculated. The variance-covariance matrix of the coefficients tends to proportion inversely to the number of observations. Thus the effect of having "n" observations for each individual tends to increase the standard errors by a factor of $\sqrt{n}$. This factor tends to overcorrect the standard error (MVA 1987).

To avoid the overestimation of the coefficients significance due to the repeated observations, the standard error of the coefficients would be multiplied by $\sqrt{n}$. Thus, the Wald test should be divided by n since the Wald test equals the square of the ratio of the variable coefficient divided by its standard error.

The Wald and the likelihood ratio (χ^2) tests have similar behaviour, and they provide identical results for large samples (Agresti 1996). Thus, the likelihood ratio (χ^2) test should be also divided by n to avoid the overestimation of the coefficients significance due to the repeated responses.

Since this modification tends to overcorrect the standard error, the values of the modified Wald and likelihood ratio tests, as well as the significance level of the variables, tend to be underestimated. Accordingly, some of the significant variables may be excluded from the model. For that reason, any variable whose significance is

0.25 or less ($p \leq 0.25$), based on the modified Wald or likelihood ratio test, will be considered as a significant variable in the model.

4.6 MODEL BUILDING

The goal of the model building is to achieve the best and most reasonable prediction model fit the data. This model should describe the relationship between the dependent variable and a set of independent variables. The model building procedure consists of four stages: (1) selection of the variables and verification of the importance of each independent variable included in the model, (2) checking collinearity among the independent variables and suggesting modifications if needed, (3) checking the linearity in the logit and suggesting modifications if required, and (4) checking if interaction terms need to be included among the independent variables in the model. These stages are described in the following subsections.

4.6.1 Variable Selection

The variable selection stage can be executed using two common methods. The first method is based on the univariate analysis of each independent variable, and selects the variables whose univariate analyses reveal a significant effect on the dependent variable. The second is to use the stepwise method in which independent variables are selected for inclusion or exclusion from the model based on statistical measures. Hosmer and Lemeshow (1989) suggested that any variable whose significance is less than 0.25 ($p \leq 0.25$) should be considered in the model.

The disadvantage of the univariate method is that, it ignores the possibility of the independent variables weakly associated with the dependent variable to become an important predictor if collected with other independent variables. The stepwise method overcomes this problem since it builds the model in a sequential fashion and allows for the examination of different combinations of the independent variables (Hosmer & Lemeshow 1989). Thus, the stepwise method was chosen to select the independent variables that significantly affect the dependent variable. After selecting the model which contains the significant independent variables, these variables were checked again considering the effect of the repeated responses. The variables which are not significant were removed and a new model was fitted and compared to the old one. This process continued until all of the significant variables were included in the model.

The stepwise procedure can be implemented by using two main approaches. The first is the forward selection with a test of backward elimination which starts by choosing an equation containing only the constant and then attempts to build up with subsequent additions of the independent variables one at time. The second approach is the backward elimination followed by a test for forward selection, which starts with equation containing all the independent variables.

The disadvantage of the forward selection approach is the possibility of excluding an independent variable that may have a statistically significant effect only when another variable is controlled or held constant. Thus, the backward elimination is recommended as the approach of stepwise regression (Menard 1995)

The backward elimination approach starts with an equation containing all the independent variables. Then, at each step, the independent variables that are not making a statistically significant contribution based on the likelihood ratio chi-square test (ie. when the likelihood ratio has a significance level greater than the cut off value) are eliminated. All the independent variables that have been removed are then examined to see if they meet the entry criteria. Any of them having a smaller significance level than the score test statistic, the chosen cut off values, is entered into the model. If no variable meets the entry criteria, the next eligible independent variables are removed from the model. This process continues until either a previously considered model is encountered or no independent variables meet the entry or removal criteria.

A critical aspect of using the stepwise logistic regression is the choice of alpha level, the cut off values, for the statistical significance to judge the importance of variables. Alpha values are recommended to be set in the range 0.15 to 0.25 rather than 0.05 since the use of 0.05 often results in excluding important variables from the model (Hosmer& Lemeshow 1989).

The SPSS package was used to carry out the backward/forward stepwise (LR) logistic regression for the collected data. The data was arranged so that each column in the input file represents one variable.

Most of the independent variables included in this study are nominal scaled and discrete. Thus it is inappropriate to treat them as continuous scaled variables. The values of these variables should be recorded by creating a new set of variables corresponding to the original categories. The number of the new variables is less than the number of variable categories by one. The omitted category is the reference category. The SPSS logistic regression procedure creates automatically new variables for the independent variables declared as categorical. The independent variables and the coding system are shown in Table 4.1.

The dummy variables, which are used to represent a single nominal/categorical variable, should be treated as a group rather than individual variables. The statistical significance of the individual dummy variables can be considered only if the design variables as a group have a statistically significant effect on the dependent variable. The statistical significance of the individual dummy variables should be interpreted as whether the effect of being in a certain category is statistically significantly different from being in the reference category (Menard 1995).

In the stepwise logistic regression the nominal independent variables were declared as categorical. The contrast for these variables was chosen indicator, which indicates the presence or absence of category membership. In the indicator coding system, the resulting coefficients of the new variables represent the effect of each category compared to the reference category and the coefficient of the reference category equals 0. Also, the first category was selected as reference category.

Table 4.1 Independent Variables Coding System and Description

Variable	Codes	Abbreviation
Accident Long Delays Accident Delays Congestion Long Delays Congestion Delays Roadworks Long Delays Roadworks Delays	1= presence 0 = absence	A1 A2 C1 C2 R1 R2
Accident # Minutes Delay Congestion # Minutes Delay Roadworks # Minutes Delay (Travel time at alternative–Travel time at usual route) Trip Length	Continuous variables	DelayAcc DelayCong DelayRw ETT TTimeusu
Age	1=17-35, 2=35-50, 3>50	Age
Gender	1= male, 2= female	Sex
Familiarity with the usual route	1=every day,2=few times aweek, 3= once a week, 4=less	Travlusu
Familiarity with the alternative routes	1= few times aweek,2=few times a month, 3= once a month, 4=less	Travlalt
Assessment of previous VMS information	0= no previous experience, 1= very satisfactory, 2=satisfactory,3=uncertain, 4=very unsarisfactory	VMS inform
Willingness to diver at later diversion points	1= divert, 2= not divert/ no later points	Divornot
Trip purpose	1=commuting,2=Shopping, 3=Entertainment, 4=others	Trippurp
Presence of Visible Queue	0= No visible queue, 1= on the usual route, 2= on the alternative.	Visq

Seven runs of the SPSS logistic regression procedure were executed to check the effect of the cut off values (alpha level), the stepwise approach (forward, backward), and to get the best model fit the data. Four runs out of these were executed using the backward stepwise logistic regression with 0.05, 0.10, 0.15, and 0.20 cut off values for both entry and removal. Another two runs were executed using the forward stepwise logistic regression with 0.10 and 0.15 cut off values for both entry and removal. The last run was carried out using the logistic regression with all of the independent variables in the model. For the purpose of assessing these models statistically, some important statistic measures are presented in Table 4.2. The full results of these models are shown in Table 4.3, Table 4.4, and Table 4.5.

Table 4.2 The Effect of Cut off Values (alpha level) of the Stepwise Regression

Model	Model χ^2 (D.F.)	Significance of χ^2	Change of χ^2 from the previous model (D.F.)	Significance of the change of χ^2	-2LL
Containing all the independent variables	660.9 (30)	0	_____	_____	4829.6
Using backward elimination α=0.10	662.8 (29)	0	1.9 (1)	0.20	4830.0
Using backward elimination α=0.05	650.1 (23)	0	12.7 (6)	0.05	4842.8
Using backward elimination α=0.15	The same results as the obtained model by using the backward elimination α=0.10				
Using backward elimination α=0.20					
Using forward selection α=0.10					
Using forward selection α=0.15					

Table 4.2 shows that, the regression models resulting from both the backward and forward stepwise approaches are the same. Also, the models are the same when the cut off values are 0.10, 0.15 and 0.20.

Table 4.2 shows also that, the change in χ^2 from the full model, containing all the independent variables, to the second mode, α = 0.10, is not statistically significant (p=0.20) indicating that the independent variables which are not included in the second model do not make any significant contribution to the prediction of the dependent variable. Also, the same table shows that, the change in χ^2 from the second model, α =0.10, to the third model, α =0.05, is statistically significant (p=0.05) indicating that the independent variables omitted from the third model have a significant contribution to the prediction of the dependent variable.

Also, Table 4.2 shows that, the value of –2LL for the second model is smaller than for the third model and is nearly the same for the first model indicating that the second model is better than the third. Thus, the second model, α= 0.10 was selected to indicate the independent variables that contribute significantly to the prediction of the dependent variable. These variables include all the independent variables except the gender.

The selected model did not consider the effect of the repeated responses. Thus, the Wald statistic for each coefficient and the model χ^2 were divided by the number of repeated observations, 8, to avoid the overestimation of the coefficients' significance due to the repeated responses. The results of this modification are shown in Table 4.6.

Table 4.6 shows that, the variables: age, familiarity with the usual routes, assessment of previous VMS information, and the trip purpose are not significant ($p>0.25$) based on the modified Wald test. These variables were removed and a new model was fitted which resulted in a modified χ^2 of 77.2 with 17 degree of freedom (d.f). The difference in the modified χ^2 between the two models, 5.7 with 12 d.f., is not statistically significant, p=0.93. Also, the coefficient values of the remaining variables did not change markedly between the two models. Accordingly, the independent variables that omitted are not significant in the prediction of the dependent variable.

Table 4.3 The Resulted Model from Using the Backward Stepwise Regression with Alpha=0.05

Initial Log Likelihood Function -2 Log Likelihood 5492.8866

-2 Log Likelihood 4842.827

	Chi-Square	df	Significance
Model Chi-Square	650.059	23	.0000

Classification Table for RESPONSE

Observed		Predicted .00 (0)	Predicted 1.00 (1)	Percent Correct
.00	0	305	623	32.87%
1.00	1	207	1649	88.85%
			Overall	70.19%

------------------------ Variables in the Equation ---------------------

Variable	B	S.E.	Wald	df	Sig	Exp(B)
A1(1)	1.4205	.1959	52.5891	1	.0000	4.1391
A2(1)	1.1338	.1915	35.0577	1	.0000	3.1075
C1(1)	1.3751	.1965	48.9940	1	.0000	3.9555
C2(1)	.8332	.1895	19.3226	1	.0000	2.3007
R1(1)	1.4983	.2007	55.7174	1	.0000	4.4743
R2(1)	.5340	.1844	8.3895	1	.0038	1.7058
DELAYACC	.0721	.0071	103.9816	1	.0000	1.0748
DELAYCO	.0630	.0070	81.7171	1	.0000	1.0650
DELAYRW	.0770	.0072	114.4662	1	.0000	1.0800
ETT	-.0554	.0056	98.2429	1	.0000	.9461
TTIMEUSU	-.0099	.0026	14.3346	1	.0002	.9901
VISQ			210.0787	2	.0000	
VISQ(1)	.3083	.0896	11.8406	1	.0006	1.3611
VISQ(2)	-.8762	.0835	109.9898	1	.0000	.4164
DIVORNOT(1)	-.5459	.0742	54.0757	1	.0000	.5793
TRAVLALT			38.4653	3	.0000	
TRAVLALT(1)	-.5077	.1139	19.8563	1	.0000	.6019
TRAVLALT(2)	-.6043	.1303	21.5080	1	.0000	.5465
TRAVLALT(3)	-.7334	.1194	37.7072	1	.0000	.4803
TRAVLUSU			16.5166	3	.0009	
TRAVLUSU(1)	.0640	.0893	.5140	1	.4734	1.0661
TRAVLUSU(2)	.4409	.1326	11.0588	1	.0009	1.5541
TRAVLUSU(3)	-.0710	.1483	.2294	1	.6320	.9314
TRIPPURP			10.6872	3	.0135	
TRIPPURP(1)	-.0789	.1319	.3576	1	.5498	.9242
TRIPPURP(2)	-.0264	.1231	.0458	1	.8305	.9740
TRIPPURP(3)	.3631	.1336	7.3872	1	.0066	1.4378
Constant	.9770	.1613	36.6948	1	.0000	

-----------------------Variables not in the Equation ----------------

Variable	Score	df	Sig
AGE	5.0797	2	.0789
AGE(1)	5.0070	1	.0252
AGE(2)	.6361	1	.4251
SEX(1)	.0015	1	.9693
VMSINFOR	7.7364	4	.1017
VMSINFOR(1)	.7749	1	.3787
VMSINFOR(2)	2.8500	1	.0914
VMSINFOR(3)	.0985	1	.7537
VMSINFOR(4)	.8050	1	.3696

Table 4.4 The Model Containing all the Independent Variables

```
Initial Log Likelihood Function -2 Log Likelihood   5490.4569
-2 Log Likelihood     4829.584

                     Chi-Square    df Significance
 Model Chi-Square       660.873    30         .0000

Classification Table for RESPONSE
                    Predicted
                  .00     1.00     Percent Correct
                    0  I    1
Observed        +-------+-------+
   .00      0   I   307 I   621 I    33.08%
                +-------+-------+
   1.00     1   I   210 I  1646 I    88.69%
                +-------+-------+
                           Overall   70.15%
```

----------------------- Variables in the Equation ---------------------

Variable	B	S.E.	Wald	df	Sig	Exp(B)
A1(1)	1.4314	.1961	53.2588	1	.0000	4.1844
A2(1)	1.1353	.1922	34.9067	1	.0000	3.1122
C1(1)	1.3852	.1974	49.2403	1	.0000	3.9956
C2(1)	.8348	.1907	19.1649	1	.0000	2.3044
R1(1)	1.5225	.2013	57.2266	1	.0000	4.5837
R2(1)	.5518	.1854	8.8593	1	.0029	1.7364
DELAYACC	.0723	.0071	102.4343	1	.0000	1.0750
DELAYCO	.0635	.0070	81.8374	1	.0000	1.0656
DELAYRW	.0776	.0072	114.5743	1	.0000	1.0807
ETT	-.0556	.0057	96.5855	1	.0000	.9459
TTIMEUSU	-.0098	.0027	13.4392	1	.0002	.9903
VISQ			210.6190	2	.0000	
VISQ(1)	.3097	.0897	11.9084	1	.0006	1.3630
VISQ(2)	-.8789	.0837	110.2644	1	.0000	.4152
AGE			5.5611	2	.0620	
AGE(1)	.1863	.0824	5.1062	1	.0238	1.2047
AGE(2)	-.0141	.1249	.0128	1	.9100	.9860
DIVORNOT(1)	-.5241	.0759	47.7136	1	.0000	.5921
TRAVLALT			37.4297	3	.0000	
TRAVLALT(1)	-.5051	.1149	19.3189	1	.0000	.6034
TRAVLALT(2)	-.5974	.1318	20.5557	1	.0000	.5502
TRAVLALT(3)	-.7310	.1205	36.7699	1	.0000	.4815
TRAVLUSU			16.0949	3	.0011	
TRAVLUSU(1)	.1033	.0926	1.2445	1	.2646	1.1088
TRAVLUSU(2)	.4647	.1356	11.7375	1	.0006	1.5915
TRAVLUSU(3)	-.0333	.1497	.0496	1	.8238	.9672
TRIPPURP			12.8899	3	.0049	
TRIPPURP(1)	-.0776	.1338	.3365	1	.5618	.9253
TRIPPURP(2)	-.0161	.1241	.0168	1	.8970	.9841
TRIPPURP(3)	.4107	.1352	9.2286	1	.0024	1.5078
VMSINFOR			8.1054	4	.0878	
VMSINFOR(1)	.0386	.1623	.0565	1	.8121	1.0393
VMSINFOR(2)	.2432	.0965	6.3463	1	.0118	1.2753
VMSINFOR(3)	.1861	.1097	2.8787	1	.0898	1.2046
VMSINFOR(4)	.3110	.1860	2.7951	1	.0946	1.3648
SEX(1)	-.0270	.0774	.1219	1	.7270	.9733
Constant	.6984	.1840	14.4018	1	.0001	

Table 4.5 The Selected Model

(resulted from using the backward stepwise regression with alpha=0.10)

```
Initial Log Likelihood Function -2 Log Likelihood   5492.8866
-2 Log Likelihood     4830.073

                         Chi-Square    df Significance
 Model Chi-Square           662.813    29         .0000

Classification Table for RESPONSE
                          Predicted
                         .00     1.00      Percent Correct
                           0  I     1
Observed               +-------+-------+
   .00        0        I   304 I   623 I    32.79%
                       +-------+-------+
   1.00       1        I   209 I  1648 I    88.75%
                       +-------+-------+
                                Overall   70.11%
```

------------------------ Variables in the Equation --------------------

Variable	B	S.E.	Wald	df	Sig	Exp(B)
A1(1)	1.4328	.1961	53.3689	1	.0000	4.1905
A2(1)	1.1367	.1921	34.9979	1	.0000	3.1165
C1(1)	1.3843	.1973	49.2220	1	.0000	3.9921
C2(1)	.8368	.1907	19.2638	1	.0000	2.3090
R1(1)	1.5245	.2012	57.3919	1	.0000	4.5929
R2(1)	.5536	.1854	8.9216	1	.0028	1.7396
DELAYACC	.0724	.0071	102.8252	1	.0000	1.0751
DELAYCO	.0637	.0070	82.2308	1	.0000	1.0657
DELAYRW	.0778	.0072	115.6071	1	.0000	1.0809
ETT	-.0556	.0057	96.7967	1	.0000	.9459
TTIMEUSU	-.0098	.0027	13.5835	1	.0002	.9902
VISQ			210.6127	2	.0000	
VISQ(1)	.3096	.0897	11.9061	1	.0006	1.3629
VISQ(2)	-.8789	.0837	110.2622	1	.0000	.4152
AGE			5.4293	2	.0662	
AGE(1)	.1821	.0817	4.9731	1	.0257	1.1998
AGE(2)	-.0145	.1249	.0135	1	.9076	.9856
DIVORNOT(1)	-.5250	.0759	47.8921	1	.0000	.5915
TRAVLALT			37.6197	3	.0000	
TRAVLALT(1)	-.5075	.1148	19.5333	1	.0000	.6020
TRAVLALT(2)	-.5993	.1317	20.6995	1	.0000	.5492
TRAVLALT(3)	-.7325	.1205	36.9482	1	.0000	.4807
TRAVLUSU			16.0474	3	.0011	
TRAVLUSU(1)	.0988	.0913	1.1700	1	.2794	1.1038
TRAVLUSU(2)	.4623	.1354	11.6665	1	.0006	1.5877
TRAVLUSU(3)	-.0365	.1493	.0597	1	.8069	.9642
TRIPPURP			12.8969	3	.0049	
TRIPPURP(1)	-.0805	.1337	.3631	1	.5468	.9226
TRIPPURP(2)	-.0156	.1240	.0158	1	.9000	.9845
TRIPPURP(3)	.4100	.1352	9.1930	1	.0024	1.5068
VMSINFOR			8.0804	4	.0887	
VMSINFOR(1)	.0372	.1622	.0526	1	.8186	1.0379
VMSINFOR(2)	.2421	.0964	6.3004	1	.0121	1.2739
VMSINFOR(3)	.1867	.1097	2.8956	1	.0888	1.2052
VMSINFOR(4)	.3116	.1861	2.8023	1	.0941	1.3656
Constant	.6958	.1838	14.3245	1	.0002	

--------------- Variables not in the Equation ----------------

Variable	Score	df	Sig
SEX(1)	.1201	1	.7289

Table 4.6 Modified Wald Test and Chi-Square According to the Repeated Responses for the Selected Model

	Chi-Square	df	Significance	
Model Chi-Square	82.9	29	<.005	
Variable	B	Wald	df	Sig
A1(1)	1.4328	6.7	1	.01
A2(1)	1.1367	4.4	1	.04
C1(1)	1.3843	6.2	1	.008
C2(1)	.8368	2.4	1	.13
R1(1)	1.5245	7.2	1	.005
R2(1)	.5536	1.1	1	.26
DELAYACC	.0724	12.9	1	<.005
DELAYCO	.0637	10.3	1	<.005
DELAYRW	.0778	14.5	1	<.005
ETT	-.0556	12.1	1	<.005
TTIMEUSU	-.0098	1.8	1	.19
VISQ		26.3	2	<.005
VISQ(1)	.3096	1.5	1	.23
VISQ(2)	-.8789	13.8	1	<.005
AGE		0.7	2	.68
AGE(1)	.1821	0.6	1	.45
AGE(2)	-.0145	0.002	1	.94
DIVORNOT(1)	-.5250	6.0	1	.015
TRAVLALT		4.7	3	.19
TRAVLALT(1)	-.5075	2.4	1	.13
TRAVLALT(2)	-.5993	2.6	1	.11
TRAVLALT(3)	-.7325	4.6	1	.03
TRAVLUSU		2.0	3	.60
TRAVLUSU(1)	.0988	0.15	1	.72
TRAVLUSU(2)	.4623	1.5	1	.23
TRAVLUSU(3)	-.0365	0.008	1	.93
TRIPPURP		1.6	3	.68
TRIPPURP(1)	-.0805	0.05	1	.094
TRIPPURP(2)	-.0156	0.002	1	.93
TRIPPURP(3)	.4100	1.2	1	.26
VMSINFOR		1.01	4	.90
VMSINFOR(1)	.0372	0.007	1	.93
VMSINFOR(2)	.2421	0.79	1	.40
VMSINFOR(3)	.1867	0.36	1	.62
VMSINFOR(4)	.3116	0.35	1	.62
Constant	.6958	1.8	1	.19

Table 4.7 shows the new model results which include the modified Wald test and its significance for each independent variable in the model. The modified Wald test shows that, all independent variables are statistically significant ($p \leq 0.25$). Thus, all independent variables in this model should be kept in the model as they significantly affect the dependent variable. These variables are: all the variables related to the displayed severity and its cause, extra travel time, trip length, the visible queue,

willingness to divert at next diversion points and familiarity with the alternative routes. The new model will be called the basic model in the next sections.

Table 4.7 The Basic Model

Initial Log Likelihood Function -2 Log Likelihood 5492.8866
-2 Log Likelihood 4875.397

	Chi-Square	df	Significance
Model Chi-Square	617.490	17	00
Modified Chi-Square	77.19		

Classification Table for RESPONSE

		Predicted .00 (0)	Predicted 1.00 (1)	Percent Correct
Observed .00	0	296	631	31.93%
Observed 1.00	1	200	1657	89.23%
			Overall	70.15%

---------------------- Variables in the Equation ----------------

Variable	B	S.E.	Modified Wald	df	Sig	Exp(B)
A1(1)	1.4079	.1954	6.5	1	.011	4.0875
A2(1)	1.1068	.1904	4.2	1	.04	3.0245
C1(1)	1.3355	.1952	6.1	1	.013	3.8018
C2(1)	.8059	.1885	2.3	1	.13	2.2386
R1(1)	1.4571	.1991	6.7	1	.01	4.2936
R2(1)	.5216	.1829	1.2	1	.25	1.6848
DELAYACC	.0710	.0070	12.7	1	<.001	1.0736
DELAYCO	.0611	.0069	9.8	1	.002	1.0630
DELAYRW	.0755	.0071	14.0	1	<.001	1.0785
ETT	-.0576	.0055	13.6	1	<.001	.9440
TTIMEUSU	-.0098	.0026	1.8	1	.17	.9902
VISQ			26.1	2	<.001	
VISQ(1)	.3060	.0893	1.5	1	.22	1.3580
VISQ(2)	-.8697	.0832	13.7	1	<.001	.4191
DIVORNOT(1)	-.5479	.0730	7.0	1	.008	.5782
TRAVLALT			4.3	3	.23	
TRAVLALT(1)	-.4654	.1121	2.2	1	.14	.6279
TRAVLALT(2)	-.4917	.1253	1.9	1	.17	.6116
TRAVLALT(3)	-.6685	.1141	4.3	1	.04	.5125
Constant	1.0643	.1575	5.7	1	.02	

4.6.2 Checking Collinearity Among Variables

The problem of collinearity arises with the existence of any correlation among the independent variables. Perfect collinearity exists if at least one of the independent variables is a linear combination of the others. Perfect collinearity is rare, while collinearity less than perfect is common. As collinearity increases among independent variables, the standard errors for the regression coefficients tend to be large. Also, collinearity often results in unreasonably high values of the regression coefficients. Thus, only as a rough guide, collinearity check should be carried out if the regression coefficients are greater than 2 (Menard 1995).

Menard (1995) suggested that examining the collinearity should be a standard part of the logistic regression analysis since this check provides valuable information about the potential problems in the analysis.

The LIMDEP package (Greene 1998) was used to examine collinearity among the independent variables since it reveals any problem of collinearity in the trace file. The data was arranged, in an Excel file, so that each column in the input file represents one variable. Also, three design (dummy) variables were created for the familiarity with alternative routes variable which contains four categories. These variables called Travelaf, Travelao, and Travelal representing few times a month, once a month, and less respectively. The fourth category, few times a week, was considered as the reference category. In addition, two dummy variables were created for the visible queue variable which contains three categories. These variables called Visqusu, and Visqalt representing presence of visible queue on the usual route and the alternative respectively. The third category, no visible queue, was considered as the reference category

The logistic regression for the data was carried out in LIMDEP using the Logit model. The commands, which have written in the text editing window, are shown in Table 4.8. The LHS contains the dependent variable while the RHS contains the independent variables. The variable one was used in the RHS to request a constant term in the model.

The output of the logistic regression model, which contains the estimated coefficients, the standard error, t-ratio, Chi-square, and log likelihood, are shown in Table 4.9. The estimated coefficients, Chi-square and log likelihood are the same as those resulted from the SPSS package which appear in Table 4.7.

Table 4.8 Commands in the Text Editing Window of LIMDEP

```
READ; File = c:/colinearitydata.xls; Nvar = 26; Names=
response, tripp, TTusual, TTalt, DelayAcc, DelayRw, DelayCo,
A1, A2, R1, R2, C1, C2, Laterp, Divertor, Exper, vmsinfo,
Travelus, TravelaF, Travelao, TravelaL, Age, Sex, Visqusu,
visqalt, ett$
Open; output=c:/tt $

logit; LHS= response

;Rhs= A1, A2, R1, R2, C1, C2, DelayAcc, DelayRw, DelayCo,
ett, TTusual, visqusu, visqalt, Divertor, TravelaF, TravelaO,
TravelaL, one$
```

Table 4.9 LIMDEP Output for the Logistic/Logit Regression Model

```
+----------------------------------------------+
| Multinomial Logit Model                      |
| Maximum Likelihood Estimates                 |
| Iterations completed                5        |
| Log likelihood function     -2437.698        |
| Restricted log likelihood   -2746.443        |
| Chi-squared                  617.4896        |
| Degrees of freedom                 17        |
| Significance level           .0000000        |
+----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
	Characteristics in numerator of Prob[Y = 1]			
Constant	1.061235104	.18289894	8.816	.0000
A1	1.408299842	.19545553	7.205	.0000
A2	1.107067911	.19036824	5.815	.0000
R1	1.457516984	.19907458	7.321	.0000
R2	.5218768172	.18295046	2.853	.0043
C1	1.335817300	.19524264	6.842	.0000
C2	.8061341214	.18848890	4.277	.0000
DELAYACC	.7104498235E-01	.70402584E-02	10.091	.0000
DELAYRW	.7555931448E-01	.71392946E-02	10.584	.0000
DELAYCO	.6109797890E-01	.69170319E-02	8.833	.0000
ETT	-.5760659836E-01	.55280879E-02	-10.421	.0000
TTUSUAL	-.9799497913E-02	.25840400E-02	-3.792	.0001
VISQUSU	.3061360142	.89308475E-01	3.428	.0006
VISQALT	-.8697799856	.83174641E-01	-10.457	.0000
DIVERTOR	-.5480023113	.73023672E-01	-7.504	.0000
TRAVELAF	-.4655649928	.11215764	-4.151	.0000
TRAVELAO	-.4919066612	.12534062	-3.925	.0001
TRAVELAL	-.6687768543	.11408939	-5.862	.0000

(Note: E+nn or E-nn means multiply by 10 to + or -nn power)

Frequencies of actual & predicted outcomes

Actual	Predicted 0	Predicted 1	Total
0	296	631	927
1	200	1657	1857
Total	496	2288	2784

Table 4.10 shows the trace file, which does not report any problem of collinearity among the independent variables of the model.

Table 4.10 The Trace File

```
+=============================================================================+
|                          LIMDEP Execution Trace                  Page   1 |
+=============================================================================+
 Line   Program Instruction
 ----   ----------------------------------------------------------------------
    1   RESET
    1   READ; File = c:/colinearitydata.xls; Nvar = 26; Names= res
        Open; output=c:/tt $
                        There are  26 variables in the data work area.
    2   logit; LHS= response
        ;Rhs=one,A1,A2,R1,R2,C1,C2,DelayAcc, Delay Rw,Delay Co,ett, TTusual,vis
        Entering iterative search for function optimizers.
        Begin main iterations for optimization.
        Normal exit from iterations. Exit status=0.
        Exit from iterative procedure.    5 iterations completed.
        Exit status appears above.
        Exit status for this model command is   .0.
```

4.6.3 Checking the Linearity in the Logit

At the variable selection stage, the logistc regression model was assumed to have a linear form, ie. each independent variable has a linear relationship with the logit. This assumption is common and acceptable at this stage as indicated by Hosmer and Lemeshow (1989). But, after finishing the variable selection stage and identifying the important independent variables to be included in the model, this assumption should be checked and the appropriate modifications should be implemented. The linearity assumption in the logit should be checked for all the continuous independent variables included in the model.

There are several techniques for examining the linearity in the relationship between the logit, the dependent variable, and each independent variable. One of them is the Box-Tidwell transformation described by Hosmer amd Lemeshow (1989). In this technique a term of the form "x*Ln(x)", where x represent the continuous independent variable, is added to the model. If the coefficient of this variable is statistically significant, there is evidence of non-linearity in the relationship between x and the logit. However, the Box-Tidwell technique does not specify the form of the non-linearity in the relationship. To specify the form of the non-linear relationship, one of the two next techniques should be further applied.

The first technique is to group the continuous independent variable data into several categories based on quartiles or less of its distribution. For each group, the logit of the average value of the dependent variable is plotted versus the group mid point. If there is linear relationship between the logit and the independent variable, the plotted points will fall on a straight line. Deviations from straight line indicate the non-linearity of the relationship. The form of the relationship between the independent variable and the logit can be concluded by looking carefully at the resulting scatter plot (Hosmer & Lemeshow 1989).

To carry out the above technique, the following steps are required:

a- Group the continuos independent variable data into several categories/groups

b- For each group:
   i- Compute the average value of the dependent variable
   ii- Compute the logit of the average value calculated at the previous step

c- Plot the mid point for each group versus the logit of the average value of the independent variable

d- Examine this scatter plot carefully to conclude the form of the relationship between the independent variable and the logit.

If the form of the relationship can not be concluded from the previous technique, the orthogonal polynomial technique can be used. In this technique, the continuous independent variables are treated as categorical variables and the orthogonal polynomial contrast is used to test for linear, quadratic, cubic and higher order effects on the logistic regression model. The Wald test for the estimated logistic regression coefficients is used to test for the significance of the components of trend. If the Wald test for the first category is significant, then the relationship between the continuous independent variable and the dependent variable is linear and if the Wald test for the second category is significant, then the relationship is quadratic. In this technique, the mid points of the continuous variable groups should be nearly equally spaced (Hosmer & Lemeshow 1989). To carry out this technique, the following steps are required:

a- Group the continuos independent variable data into several categories/groups

b- Apply the logistic regression in which the continuous independent variable, which grouped at step a, is declared as a categorical variable with orthogonal polynomial contrast.

c- Examine the Wald statistic for the resulting coefficients of the independent variable categories.

The Box-Tidwell technique was applied to check the linearity for the continuous independent variables in the basic model. For the ETT, the term "ETT*Ln(ETT)" was added to the basic model and resulted in a new model with modified χ^2 of 77.24 and 18 degree of freedom, d.f. The difference of the modified χ^2 between the resulted model and the basic model, 0.05 with 1 d.f., is not statistically significant, p=0.82. Also, the coefficient values of the variables have not changed markedly between the two models. Thus, the coefficient of the added term is not statistically significant. Accordingly, it is accepted that the relationship between the ETT and the logit is linear.

The effect of adding the term " TTimeusu *Ln(TTimeusu)" to the basic model is also not statistically significant since the difference of modified χ^2, 0.22 with 1 d.f., is not statistically significant, p=0.64. Also, the coefficient values of the variables have not any markedly changes between the two models. Thus, it is accepted that the relationship between the independent variable "TTimeusu" and the logit is linear.

For the independent variable delayco, the effect of adding the term " delayco *Ln(delayco)" to the basic model is also not statistically significant since the difference of modified χ^2, 0.04 with 1 d.f., is not statistically significant, p=0.84. Also, the coefficient values of the variables have not any markedly changes between the two models. Thus, the relationship between the independent variable "delayco" and the logit is accepted to be linear.

It was also found that, the effect of adding the term " delayacc *Ln(delayacc)" to the basic model is not statistically significant since the difference of modified χ^2, 0.3 with 1 d.f., is not statistically significant, p=0.58. Also, the coefficient values of the variables have not any markedly changes between the two models. Thus, the relationship between the independent variable "delayacc" and the logit is accepted to be linear.

For the continuous independent variable delayrdwk, the effect of adding the term "delayrdwk *Ln(delayrdwk)" to the basic model is also not statistically significant since the difference of modified χ^2, 0.005 with 1 d.f., is not statistically significant, p=0.94. Also, the coefficient values of the variables have not any markedly changes between the two models. Thus, it is accepted that the relationship between the independent variable "delayrdwk" and the logit is linear.

4.6.4 Variable Interactions

The interaction between any two independent variables indicates that the effect of one on the dependent variable varies with the values of the other independent variable.

In the basic model the variables: willingness to divert at next diversion points and familiarity with the alternative routes are expected to have a potential to interact with the other variables included in the model. Accordingly, a total of 23 interaction terms can be included in the model as shown in Table 4.11.

To assess the contribution of the interaction terms to the model, the effect of including each interaction term was examined by adding this term, the product of the variables, to the basic model and comparing the modified χ^2 for the resulting model and the basic model. If the difference between the two model chi-squares is significant, then the interaction term has a significant effect on the prediction of the dependent variable.

A total of 23 runs of the SPSS logistic regression procedure were carried out to examine the effect of the interaction terms, and the results of adding each interaction term to the basic model are shown in Table 4.11.

Table 4.11 Statistic Measures Resulting from Adding Each Interaction Terms to the Basic Model

Interaction term	Modified χ^2 (d.f.)	Difference of Modified χ^2 from basic model (d.f.)	Significance of Modified χ^2 difference
Basic Model	77.19 (17)	------------	-------------
divornot *A1	77.20 (18)	0.01 (1)	0.92
divornot *A2	77.20 (18)	0.01 (1)	0.92
divornot *C1	78.28 (18)	1.09 (1)	0.30
divornot *C2	77.23 (18)	0.04 (1)	0.84
divornot *R1	77.41 (18)	0.22 (1)	0.64
divornot *R2	77.60 (18)	0.41 (1)	0.52
divornot *delayacc	77.48 (18)	0.29 (1)	0.59
divornot *delayco	77.58 (18)	0.39 (1)	0.53
divornot *delayrw	77.26 (18)	0.07 (1)	0.79
divornot*ETT	77.30 (18)	0.11 (1)	0.74
divornot *Vis-q	80.50 (19)	3.31 (2)	0.19
divornot *travlalt	78.39 (20)	1.2 (3)	0.75
travlalt *A1	77.95 (20)	0.76 (3)	0.86
travlalt *A2	78.81 (20)	1.62 (3)	0.65
travlalt *C1	77.36 (20)	0.17 (3)	0.98
travlalt *C2	77.28 (20)	0.09 (3)	0.99
travlalt *R1	77.60 (20)	0.41 (3)	0.94
travlalt *R2	77.41 (20)	0.22 (3)	0.97
travlalt *delayacc	78.23 (20)	1.04 (3)	0.79
travlalt *delayco	77.49 (20)	0.30 (3)	0.96
travlalt *delayrw	77.63 (20)	0.44 (3)	0.93
travlalt *ETT	78.40 (20)	1.21 (3)	0.75
travlalt *Vis-q	80.28 (23)	3.09 (4)	0.54

Table 4.11 shows that, the only interaction term that can be added to the basic model based on a significance level of 0.25 or less is divornot *Vis-q. Adding the term divornot *Vis-q to the basic mode resulted in a new model with modified χ^2 of 80.5 and 19 d.f. The difference of the modified χ^2 between the resulted model and the basic model, 3.31 with 2 d.f., is statistically significant, p=0.19. The estimated coefficients and the modified Wald test for the model including the interaction term are shown in Table 4.12.

Table 4.12 The Model from the Univariate Analysis of Interactions

Initial Log Likelihood Function -2 Log Likelihood 5492.8866
-2 Log Likelihood 4848.827

	Chi-Square	df	Significance
Model Chi-Square	644.059	19	.0000

Classification Table for RESPONSE

		Predicted .00 (0)	Predicted 1.00 (1)	Percent Correct
Observed .00	0	322	605	34.74%
Observed 1.00	1	216	1641	88.37%
			Overall	70.51%

-------------------- Variables in the Equation --------------------
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Variable	B	S.E.	Modified Wald	df	Sig	Exp(B)
A1(1)	1.4075	.1958	6.46	1	.01	4.0856
A2(1)	1.1031	.1910	4.17	1	.04	3.0135
C1(1)	1.3368	.1956	5.84	1	.016	3.8070
C2(1)	.7993	.1894	2.23	1	.013	2.2240
R1(1)	1.4583	.1995	6.68	1	.01	4.2988
R2(1)	.5129	.1839	1.2	1	.25	1.6702
DELAYACC	.0708	.0070	12.67	1	<.001	1.0734
DELAYCO	.0609	.0069	9.68	1	.002	1.0628
DELAYRW	.0753	.0071	13.91	1	<.001	1.0782
ETT	-.0576	.0055	13.49	1	<.001	.9440
TTIMEUSU	-.0096	.0026	1.8	1	.17	.9904
VISQ			25.8	2	<.001	
VISQ(1)	.4459	.1208	1.7	1	.19	1.5618
VISQ(2)	-1.0796	.1060	12.96	1	<.001	.3397
DIVORNOT(1)	-.6751	.1254	3.63	1	.06	.5091
TRAVLALT			4.33	3	.22	
TRAVLALT(1)	-.4647	.1122	2.14	1	.14	.6283
TRAVLALT(2)	-.4954	.1253	1.95	1	.16	.6093
TRAVLALT(3)	-.6710	.1141	4.32	1	.04	.5112
DIVORNOT * VISQ			3.31	2	.19	
INT_1	-.3071	.1819	0.36	1	.55	.7356
INT_2	.5714	.1700	1.1	1	.29	1.7707
Constant	1.1157	.1632	5.8	1	.016	

4.7 ASSESSMENT THE MODEL FIT

The purpose of assessing the model fit is to test whether the predicted values give a reasonable description of the observed values. Assessing the model fit should include evaluating the fit of the overall model in addition to the accuracy of prediction. Evaluation the overall model can be carried out using G_M/model χ^2, -

2LL, and R^2_L. On the other hand, the evaluation of prediction accuracy can be carried out using τ and λ parameters (Menard 1995).

R^2_L is a proportional reduction in χ^2 or in the absolute value of the log-likelihood measure. It indicates the amount of reduction in the goodness of fit, D_o chi-square statistic, as a result of including the independent variables in the model. R^2_L is similar to R^2 in the linear regression analysis. The values of R^2_L vary between 1 for a perfect model and 0 for the model in which the independent variables have no contribution to the prediction of the dependent variable. R^2_L can be calculated as the model χ^2 divided by D_o which is called "initial log-likelihood function-2 log-likelihood" in SPSS logistic regression (Menard 1995).

In the logistic regression, R^2_L is not the proportion of variance explained by the model as in the linear analysis. But, R^2_L is a rough approximation for assessing the predictive efficiency (Demaris 1992). Also, Menard (1995) stated that a value of 0.3 for R^2_L indicate a moderately strong relationship between the dependent variable and the independent variables.

Hosmer and Lemeshow 1989 stated that the R^2_L value is not a measure for the goodness of fit, since it is an expression of the likelihood ratio test which compares the fitted values under two models rather than comparing the observed and fitted values for the same model. For this reason, the values of R^2_L were calculated but it was not considered as an important factor in assessing the model fit.

Lambda, λ, and τ are proportional reduction in error measures. A value of 1 for either λ or τ indicates that all the cases are correctly predicted as the data. While the negative values of λ or τ indicate that the prediction model makes worse predictions for the cases and also indicate a proportional increase in error.

Lambda λ can be calculated as the number of cases in the smaller observed category (296+631=927 for the basic model, Table 4.7) minus the number of cases incorrectly predicted by the model (200+631=831 for the basic model), divided by the number of cases in the smaller observed category. While τ can be calculated according the following steps:

a- Calculate the sum of cases in each of the two categories for the observed values

b- Multiply the product of the two sums, obtained from the previous step, by two

c- Divide the value obtained from the previous step by the total number of cases

d- Calculate τ as the value obtained from the previous step minus the number of cases incorrectly predicted by the model, divided by the value obtained from the previous step. The result from this step is τ (Menard 1995).

The statistical significance for both λ, and τ can be tested using the statistic d which is approximately normally distributed. This test indicates whether the model predictions differ significantly from the observed data. The statistic d for λ can be calculated according to the following steps (Menard 1995):

a- Calculate the number of cases in the smaller observed category

b- Divide the value obtained from the previous step by the total number of cases (P_1)

c- Calculate the number of cases incorrectly predicted by the model

d- Divide the value obtained from the previous step by the total number of cases (P_2)

e- Calculate the statistic d as follows:

$$d = \frac{P_1 - P_2}{\sqrt{\frac{P_1(1-P_1)}{total\ number\ of\ cases}}}$$

The statistic d for τ can be calculated according to the following steps:

a- Calculate the sum of cases in each of the two categories for the observed values b- Multiply the product of the two sums, obtained from the previous step, by two

c- Divide the value obtained from the previous step by square the total number of cases (P_1)

d- Calculate the number of cases incorrectly predicted by the model

e- Divide the value obtained from the previous step by the total number of cases (P_2)

f- Calculate the statistic d as follows:

$$d = \frac{P_1 - P_2}{\sqrt{\frac{P_1(1-P_1)}{total\ number\ of\ cases}}}$$

Assessing the model fit was carried out for the model with interaction as well as the basic model. Table 4.13 shows the values: model χ^2, -2LL, λ, τ, d (for λ and τ), and R^2_L for both models.

Table 4.13 Assessment of Fit Measures for the Final and the Basic Model

	Model with Interaction	Basic Model
Modified χ^2 (d.f.)	80.50 (19)	77.19 (17)
Significance of χ^2	<0.001	<0.001
-2LL	4848.8	4875.4
λ	0.11	0.1
τ	0.34	0.33
d (for λ)	4.26	3.86
d (for τ)	15.85	15.47
Significance of λ	<0.001	<0.001
Significance of τ	<0.001	<0.001
R^2_L	0.12	0.11

Table 4.13 shows that the model χ^2 is significant for both models. There is only a minor difference in the –2LL value between the two models indicating that both

models provide a similar fit for the data. The large values of the –2LL indicate that neither model fit the data very well but the focus should be on the Model χ^2 rather than –2LL as recommended by Menard (1995). Thus, it is accepted that both models fit the data well since the significance of χ^2 is <0.001. The values of λ and τ for the model with interaction indicate good prediction efficiency and are slightly higher than those for the basic model. The significance of λ and τ indicates a strong relationship between the observed and predicted classification of cases for both models. The value of R^2_L for the model with interaction equals 0.12, and it is slightly higher than the basic model.

It can be concluded that both models have nearly the same prediction efficiency and data fit. Thus, because of its simpler form, the basic model was selected as the final model to be used in predicting the probability of diversion in the presence of the VMS information.

4.8 Model Validation

The validity of the model aims to assess the validity of the developed model in predicting the probability of diversion in presence of VMS information for any car trip in the Sydney Metropolitan Region. This process was carried out by using the developed model to estimate the predicted response, probability of diversion, for each case of the validation sample which was not used in the model development. Then, the predicted response was compared with the actual response for all cases of the validation sample.

The developed model predicts the probability of diversion which indicates how likely the event is to occur and can be any value between 0 and 1. On the other hand, the actual response is a binary decision, divert or not. Thus, the predicted probability of diversion should be transformed to a decision, divert or not, in order to compare the predicted and the actual responses. The method used for that purpose, as suggested by DeMaris (1992), is to assume that a driver is diverting if the probability of diversion is greater than 0.5 and not diverting when the probability of diversion is less than or equal 0.5.

The following section to be added after section 4.8

4.9 The Impact of Excluding the Personal (Behavioral) Parameters from the Diversion Model

As stated in the literature review chapter, route choice is a result of the drivers' decision-making process which is a rational behaviour since it relates to a certain driver and changes for different drivers for the same trip. Thus, the selected route results from the personal characteristics of the driver and those of the transport system. In other words, route choice is a function of the driver's subjective needs, perceptions, experience, and preferences; and of the physical environment with its objective alternatives and their characteristics. In addition, most of the developed models in the literature, which predict the effect of driver information systems including VMS, contain the parameter: drivers' familiarity with the network. Also, several models in the literature contain different behavioural parameters such as: drivers' personality (adventure and discovery), listening propensity to traffic information, and perception of the reliability of their routes (eg. Khattak et al 1993a; Emmerink et al 1996; Abdel-aty et al 1995; Khattak et al 1994; Abdel-aty et al 1997).

For these reasons, we strongly believe that the driver personal (behavioural) parameters are quite important in predicting the driver's response to VMS information. However, we have carried out analysis to obtain the impact of excluding these parameters. That analysis was done by calibrating a restricted diversion model where the driver personal (behavioural) parameters are excluded, and assessing the validity of that model. The model results, which include the estimated coefficients, standard error, modified Wald test and its significance for each independent variable, modified Chi-square and log likelihood, are shown in Table 4.14. The validation process of the restricted model shows that 91 cases out of 440 have actual responses different from the predicted (ie. the percentage of error in the response prediction is 20.7%). Accordingly, the analysis indicates that the prediction accuracy decreased, as expected, as a result of excluding the driver personal parameters. Although the accuracy reduction is not too large, 5.2%, we recommend the model including the driver personal parameters.

Table 4.14 The Restricted Diversion Model (excluding drivers' personal parameters)

Initial Log Likelihood Function -2 Log Likelihood 5492.8866
-2 Log Likelihood 4966.748

	Chi-Square	df	Significance
Model Chi-Square	526.138	13	.0000
Modified Chi-Square	65.77		

Classification Table for RESPONSE

		Predicted .00 (0)	Predicted 1.00 (1)	Percent Correct
Observed .00	0	272	654	29.37%
1.00	1	189	1669	89.83%
			Overall	69.70%

------------------ Variables in the Equation --------------------

Variable	B	S.E.	Modified Wald	df	Sig	Exp(B)
A1(1)	1.3155	0.1925	5.8360	1	.02	3.7267
A2(1)	1.0734	0.1883	4.0603	1	.04	2.9252
C1(1)	1.2865	.1925	5.5823	1	.02	3.6201
C2(1)	.8497	.1865	0.3455	1	.56	2.3389
R1(1)	1.4400	.1966	6.7031	1	.01	4.2206
R2(1)	.5738	.1808	0.1338	1	.71	1.7751
DELAYACC	.0713	.0070	13.1332	1	<.005	1.0739
DELAYCO	.0609	.0068	9.9458	1	<.005	1.0628
DELAYRW	.0743	.0070	13.9191	1	<.005	1.0772
ETT	-.0648	.0054	17.8576	1	<.005	.9372
TTIMEUSU	-.0127	.0025	3.1712	1	.07	.9874
VISQ			25.6894	2	<.005	
VISQ(1)	.3018	.0883	1.4593	1	.23	1.3523
VISQ(2)	-.8491	.0821	13.3636	1	<.005	.4278
Constant	1.5280	.1306	17.1108	1	<.005	

However, the lack of input data for validating such behavioural models is a valid concern. There is little information available about driver behaviour parameters in general. This indicates that further research should be undertaken to establish the suitable range of driver behaviour parameters in Sydney, as well as in any other places where the model is to be used. Until these results are unavailable, for the driving aggression parameter, we can assume an average distribution of values. These values should be higher for people driving in congested traffic areas compared with less congested areas. Also, these values should be different from country to country where the culture and driving style are quite different.

It was found that 68 cases out of 440 have actual responses different from the predicted (ie. the percentage of error in the response prediction is 15.5%). In about 90% of these cases the predicted response was to divert as opposed to an actual response not to divert. Overall, 84.5 percent of cases were predicted correctly.

The error in the prediction of decisions may arise from the need to consider any other explanatory variable, which has a potential effect on the probability of diversion for drivers having trips of different origins, destinations and travel times. However, a 15 % error is considered acceptable for the intended use of the model.

It can be concluded from the validity result of the model, that the developed model is a valid tool for predicting the probability of diversion in presence of VMS information for any car trip in Sydney Metropolitan Area.

4.9 INTERPRETING THE FINAL MODEL COEFFICIENTS

Interpreting the logistic regression coefficients is not as straightforward as the linear regression because of its function form. Thus, the interpretation of the model coefficients was carried out through two main steps as described by Liao (1994). The first step relates to the sign of the coefficients, while the second is related to the marginal effect on the odds. Odds refer to the ratio between the probability of diversion and the probability of staying on the usual route (not diverting), while odds ratio refers to the ratio of odds. Odds ratio for categorical variables is the ratio of odds for the considered category to the odds of the reference category. While, odds ratio for continuous variables represents change in the odds per unit change in the variable.

The positive sign of a coefficient indicates an increase in the probability of diversion with the increase in the explanatory variable while the negative sign indicates a decrease in the diversion probability when the explanatory variable decrease.

An odds ratio greater than 1 indicates that the odds of an event occurrence increases with the increase of the independent variable, while an odds ratio less than 1 indicates that the odds of an event occurrence decreases when the independent variable increases (Menard 1995).

In dealing with a nominal/categorical variable, the interpretation of the dummy variables, which are the different categories of the variable, is always relative to the reference category.

All of the variables related to the cause and severity of the incident displayed on the VMS have a positive sign, as shown in Table 4.7. This can be interpreted that the information about the incident cause and severity increases the diversion rate in each case. Also, the increase of the quantitative displayed delay increases the probability of diversion. The signs of the ETT and TTimeusu are negative indicating that the diversion probability decreases when the extra travel time or the trip length increase. In the presence of visible queue on the usual route the sign of Visq(1) is positive indicating an increase in the diversion, while the sign is negative when the visible queue is on the alternative route, Visq(2), indicating a decrease in the diversion. For drivers who are not willing to divert at the next potential diversion points, the sign of Divornot (1), is negative indicating a decrease in the diversion probability relative to those who are willing to divert at next diversion points. The reference category of the familiarity with alternative route variable is the most familiar drivers. Thus, the negative sign associated with the low familiarity levels, travlalt (1), travlalt (2), and travlalt (3), indicates a decrease in the diversion when the familiarity level decrease. The signs of all the coefficients are plausible.

The last column in Table 4.7, Exp(B), is the expected change in the odds of having a diversion occurring versus not occurring, per unit change in an explanatory variable, other things being fixed (Liao 1994). For categorical variables, a unit change in certain category is the difference between membership in this category and the membership in the reference category. Thus, Exp (B) is the odds ratio for the considered category versus the reference category (DeMaris 1995).

Table 4.7 shows that Exp (B) for the variable A1, accident long delay, is 4.09 indicating that the odds of diversion when the displayed message is accident long delay are 4.09 times as high as no message is displayed. Also, the odds of diversion when the displayed message is accident delay, A2, are 3.02 times as high as no message is displayed. When the displayed message is congestion long delay 'C1', congestion delay 'C2', roadworks long delay 'R1' or roadworks delay 'R2', the odds of diversion are 3.8, 2.24, 4.29, or 1.68 times as high as no message is displayed. A one-minute increase in the displayed delay when the incident type is accident 'Delayacc' increases the odds of diversion by 1.07. In addition, the odds of diversion increase by a factor of 1.06, or 1.08 when the displayed delay increases one minute if the incident type is congestion 'Delayco' or roadworks 'Delayrw' respectively. On the other hand, a one-minute increase in the extra travel time 'ETT' or the trip length on the usual route 'Ttimeusu' decreases the odds to divert by a factor of 0.94, or 0.99 respectively. The odds of diversion in the presence of visible queue on the usual route 'Visq (1)' are 1.36 times higher than in the absence of visible queue. On the contrary, odds of diversion in the presence of visible queue on the alternative route 'Visq (2)' are 0.42 times smaller than in the absence of visible queue. The odds of diversion for drivers whose are not willing to divert at next potential diversion points 'Divornot (1)' are 0.58 times smaller than for drivers willing to divert at next diversion points. The odds of diversion for drivers using alternative routes few times a month 'travlalt (1)', once a month 'travlalt (2)', or less 'travlalt (3)' are 0.63, 0.61, or 0.51 times smaller than those using alternative routes few times a week. All these odds are logical and plausible.

To analyse the effect of model coefficients/ parameters on the probability of diversion, a parameteric analysis was carried out for the different coefficients included in the model as described in chapter 5.

4.10 FORM OF THE FINAL MODEL

The final form of the developed VMS model is as follow:

$$P = \frac{1}{1 + \exp^{(-U)}}$$

U= MessageContent - 0.058*ETT - 0.01* TT + V + D + W + 1.06

where
P = Probability of diversion,
U = The relative utility of the alternative route,
MessageContent = see Figure 4.1 for parameter values,
ETT = Extra travel time under normal conditions,
TT = Trip length under normal conditions,

V = Existence of visible queue, see Figure 4.1 for parameter values,
D = Drivers' familiarity with the alternative routes, see Figure 4.1 for parameter values,
W = Drivers' willingness to divert at next potential diversion points
= -0.55 if No
= 0.0 if Yes

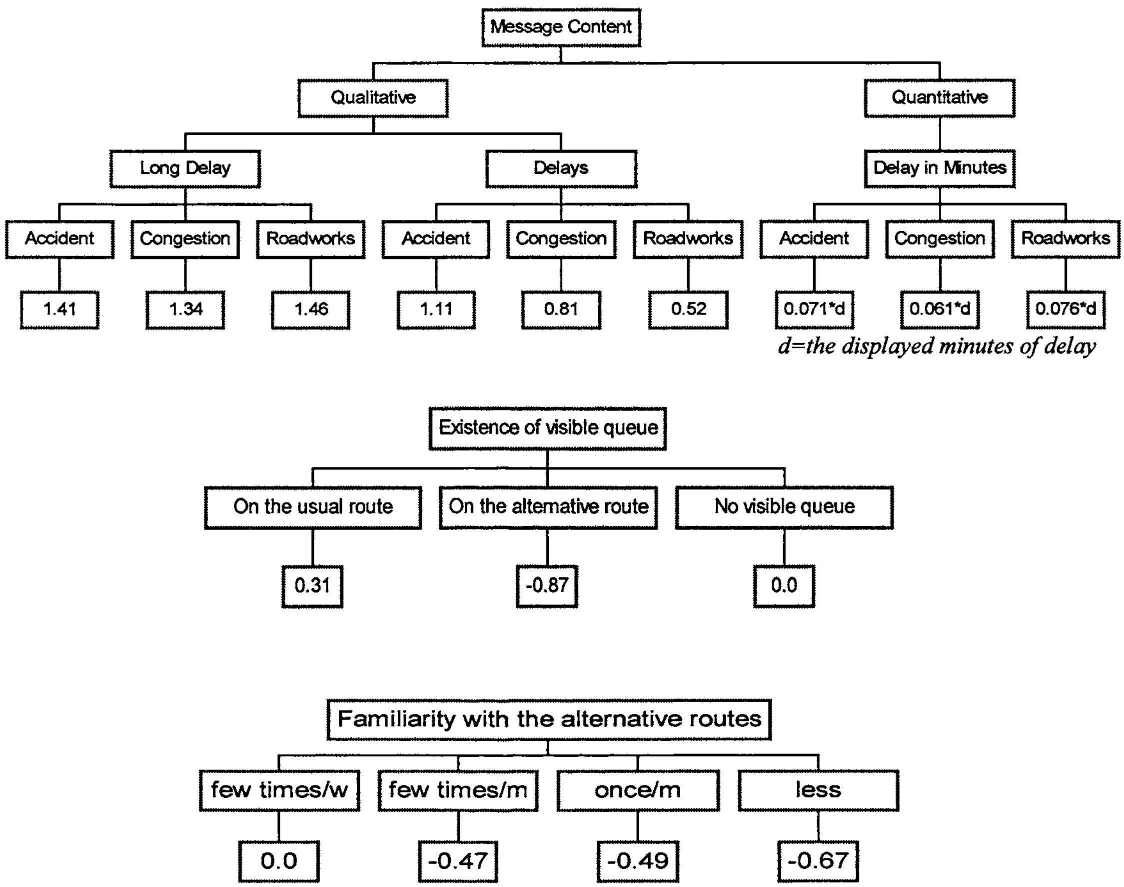


Figure 4.1 Parameter Values of the Final Model

The developed model is able to predict the probability of diversion of individual drivers in response to different VMS contents, based on a number of driver and trip attributes. However, the overall effect of the VMS on the network performance can only be estimated by predicting the route choice behaviour of every driver passing the VMS site. Thus, the developed route diversion model was incorporated into a microscopic simulation model, to explore the effect of VMS on network performance as described in chapter 6.

CHAPTER 5
PARAMETRIC ANALYSIS

The VMS model developed in the previous chapter aims to predict the probability of diversion based on a set of explanatory variables. In this chapter, a parametric analysis was carried out to analyse the effect of these variables – VMS information, and drivers and trip attributes - on the probability of diversion. This analysis is useful in exploring drivers' behaviour in response to different VMS information for different trips.

To analyse the effect of a certain explanatory variable/s, the probability of diversion should be computed for a set of values for that explanatory variable/s while controlling the other explanatory variables in the model. DeMaris (1995) suggested that the values of other explanatory variables can be set to their sample mean in case of continuous variables and to their mode in case of categorical variables.

5.1 The Effect of Message Content on the Probability of Diversion

The prediction model was used to calculate the probability of diversion for a range of VMS message content attributes, such as incident type and severity, while setting all other model parameters to the values suggested by DeMaris (1995) as follows: trip time of 28.9 minutes, extra travel time of 6.4 minute, willingness to divert at later point of 1(meaning yes, willing to divert), familiarity with the alternative route of 2 (meaning few times per month), and visible queue of 0 (meaning no visible queue).

Figure 5.1 shows the effects when the VMS message includes a quantitative indication of the delay time. It can be seen that the diversion rate increases as the displayed delay time on the usual route increases. Also, increasing the displayed delay time from 5 to 30 minutes increases the percent of diversion by about 30% for all incident types. In addition, the percent of diversion for both accident and roadworks are approximately the same and slightly higher than for the congestion.

Figure 5.2 shows that the probability of diversion is nearly the same, around 80 %, for all incident types when the incident severity indicated in the VMS message is long delay. This indicates that when drivers know that the expected delays are long, the incident type does not have a large weight in the decision-making whether or not to divert. In addition, the diversion rates for delays are less than those for long delays by 5, 10, and 19% for accident, congestion, and roadworks respectively. The percent of diversion in case of accident is higher than for congestion and roadworks when the displayed severity is delays.

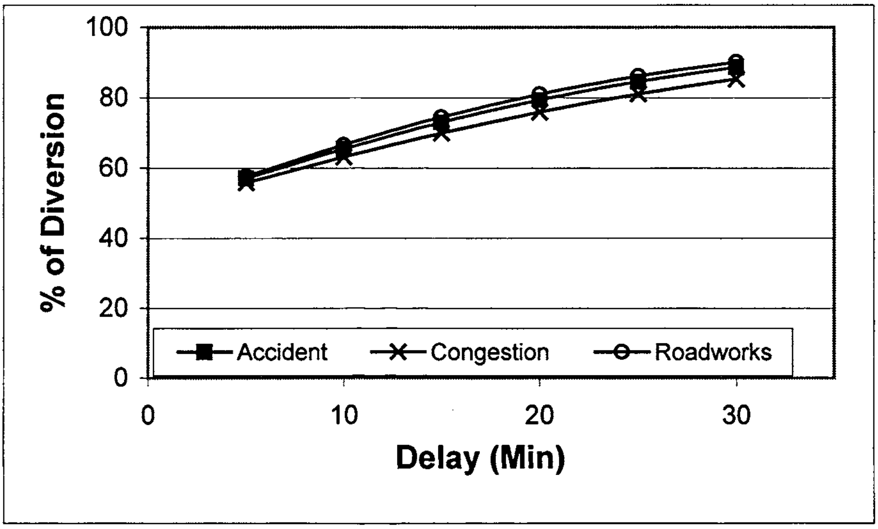


Figure 5.1 The Effect of Delay Time on the Probability of Diversion

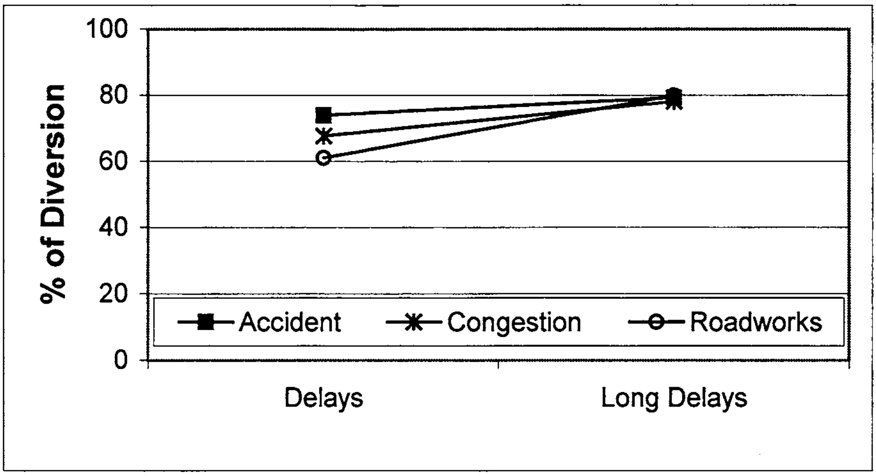


Figure 5.2 The Effect of Qualitative Delay on the Probability of Diversion

Figure 5.1 and Figure 5.2 show that the incident type does not have an obvious effect on the probability of diversion when the displayed severity is long delay and delay in minutes. That can be explained by the assumption that when drivers receive certain information about the expected delays, such as long delay or quantity of delay, they select their route according to the delay information rather than the incident type. On the other hand, the incident type has a clear effect on the diversion rate when the displayed severity is delays. This indicates that when the information about the expected delays is uncertain, such as delays, drivers put more weight to the incident type as well as to the delay information in selecting their routes. Furthermore, it is clear that the highest percent of diversion is obtained when the displayed severity is uncertain, delays, in case of accident and the lowest percent of diversion is obtained when the incident type is roadworks. This means that adding the uncertainty of an accident to the uncertainty of the expected delay results in an increase in the percent of diversion.

Figure 5.1 and Figure 5.2 show also that when the displayed severity is long delay, the percent of diversion is approximately the same as for displayed delay of 20 minute when the incident type is accident or roadworks. In addition, when the incident type is congestion, the percent of diversion for long delay is the same as for 23 minute. Thus, it can be concluded that drivers interpret a message of "long delay" as equivalent to a message of 20 minutes delays in case of accident and roadworks, and 23 minutes delays in case of congestion. Also, when the displayed severity is delays, the percent of diversion is approximately the same as for displayed delay of 15, 13 and 7 minute for the incident type of accident, congestion and roadworks respectively. Accordingly, it can be concluded that a message of "delays" is interpreted by drivers as equivalent to the effect of 15, 13, and 7 minutes delays in case of accident, congestion, and roadworks.

5.2 The Effect of Extra Travel Time and Trip Travel Time for Different VMS Information on the Probability of Diversion

The extra travel time (ETT) is the travel time difference between the alternative and the usual route under normal conditions. Previous studies have shown that the ETT has a strong effect on the route choice behaviour in the presence of the VMS information. However, most previous studies were based on one or two fixed trips, therefore the results were relevant to the given fixed trip travel time. On the other hand, this study is based on many car trips of different lengths in Sydney Metropolitan Region, and we found that the trip length - trip travel time - significantly affects the route choice behaviour in the presence of VMS information. Thus, an analysis was carried out to investigate the combined effect of the ETT and the trip travel time on the diversion rate in the presence of the provided information.

As concluded in the previous section, the incident type does not have an obvious effect on the probability of diversion when the displayed severity is long delay and delay in minutes, while it has a clear effect when the displayed severity is delays. Thus, the effect of ETT and the trip travel time was analysed for displayed severity of long delay, and 10, 15, 20, 30 minute delay for accident only, while it was analysed for the different incident types, accident, congestion, roadworks, when the displayed severity is delays. In this analysis, the variables : willingness to divert at later point, familiarity with the alternative route, and visible queue were set to values of 1, 2, and 0 respectively.

Figure 5.3 shows that, the diversion rate due to the message "accident long delay" ranges from 87% to 80% for trip travel times between 15 and 60 minute when the travel time for both the usual and the alternative routes are the same, ETT=0. As the extra travel time increases, the diversion rate decreases until it reaches 16%-11% at ETT of 60 minute for trip travel times between 15 and 60 minute.

Figure 5.4 shows that, the diversion rate due to the accident delays sign ranges from 83% to 75% for trip travel times between 15 and 60 minute when the travel time for both the usual and the alternative routes are the same. As the extra travel time increases, the diversion rate decreases until it reaches 13%-9% at ETT of 60 minute for trip travel times between 15 and 60 minute.

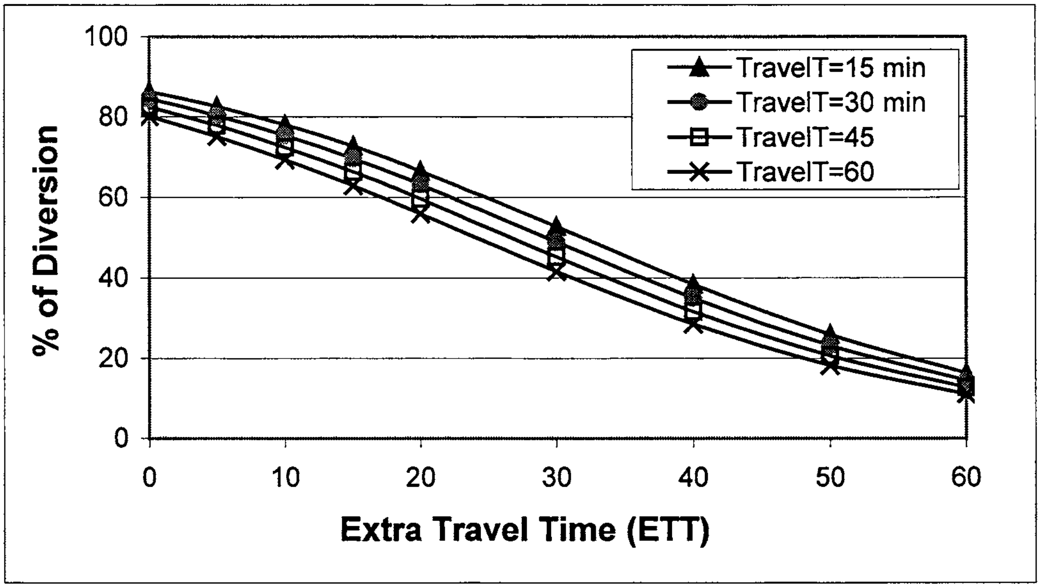


Figure 5.3 Effect of ETT and Trip Travel Time on the Probability of Diversion (Accident-Long Delay)

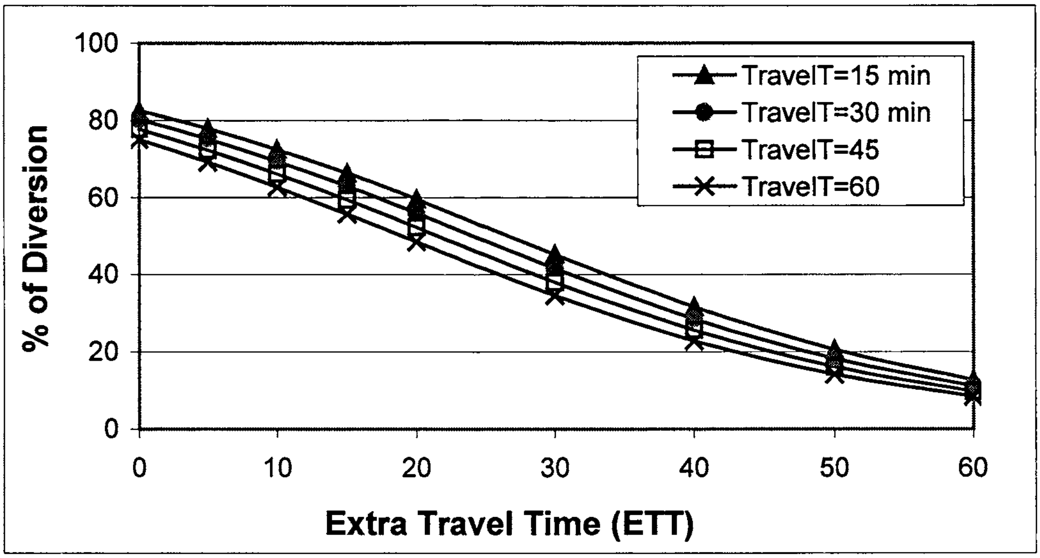


Figure 5.4 Effect of ETT and Trip Travel Time on the Probability of Diversion (Accident- Delays)

Figure 5.5, Figure 5.6, and Figure 5.7 show that the diversion rate due to the accident 10, 20, and 30 min. delay signs ranges from 76% to 66%, 87-80% and 93-89% for trip travel times between 15 and 60 minute when the travel time for both the usual and the alternative routes are the same. As the extra travel time increases, the diversion rate decreases until it reaches 9-6%, 17-11%, and 29-20% at ETT of 60 minute for trip travel times between 15 and 60 minute.

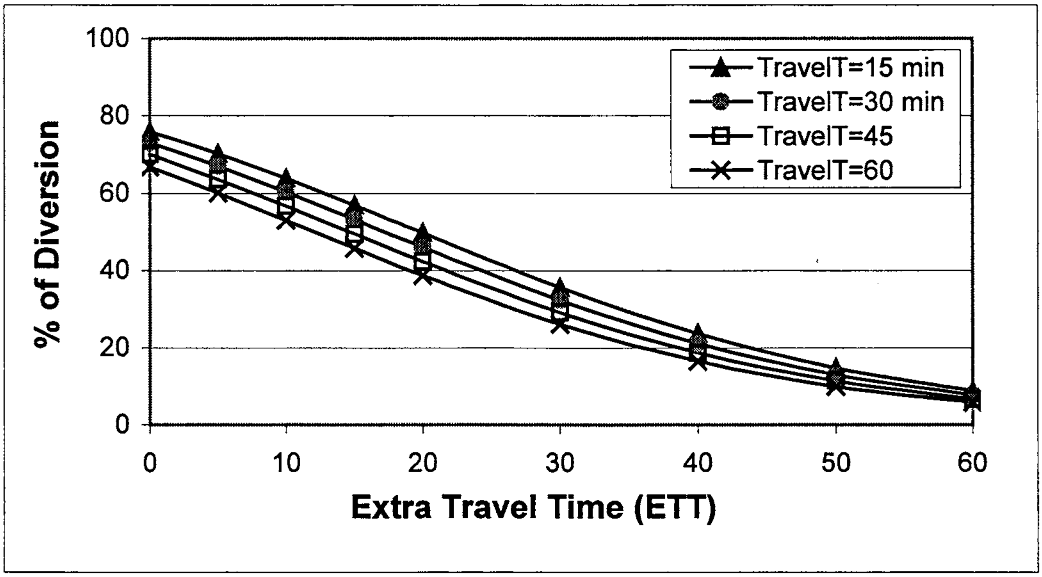


Figure 5.5 Effect of ETT and Trip Travel Time on the Probability of Diversion (Accident- 10 min. Delay)

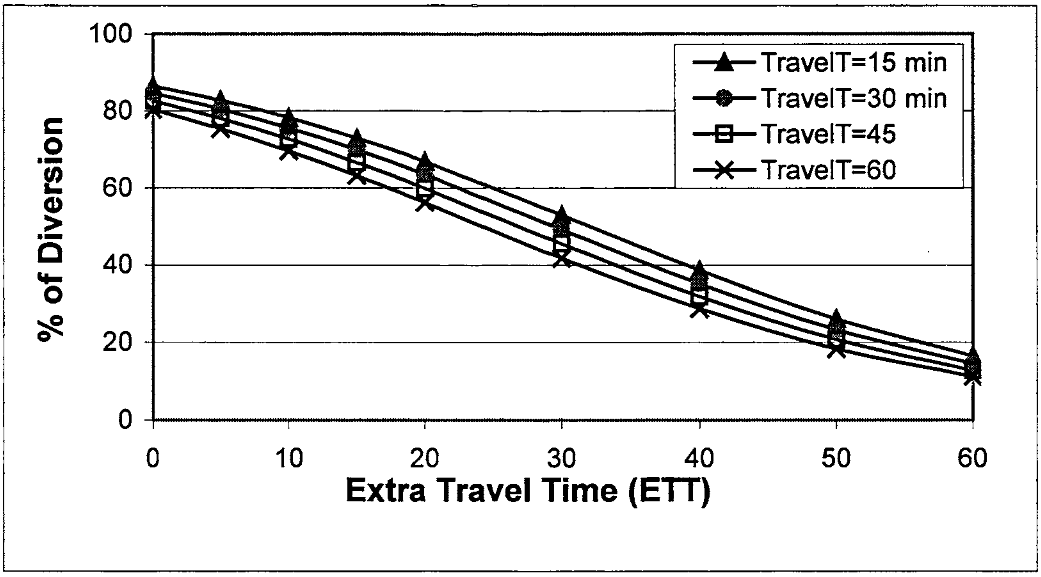


Figure 5.6 Effect of ETT and Trip Travel Time on the Probability of Diversion (Accident- 20 min. Delay)

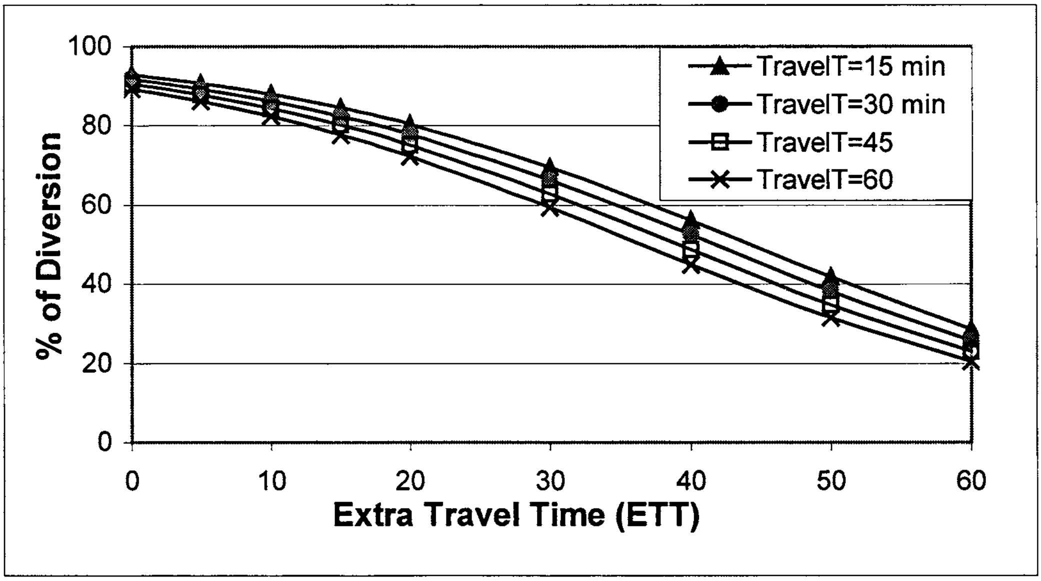


Figure 5.7 Effect of ETT and Trip Travel Time on the Probability of Diversion (Accident- 30 min. Delay)

Figure 5.8 shows that, the diversion rate due to the accident delays sign ranges from 78% to 69% for trip travel times between 15 and 60 minute when the travel time for both the usual and the alternative routes are the same. As the extra travel time increases, the diversion rate decreases until it reaches 10%-6% at ETT of 60 minute for trip travel times between 15 and 60 minute.

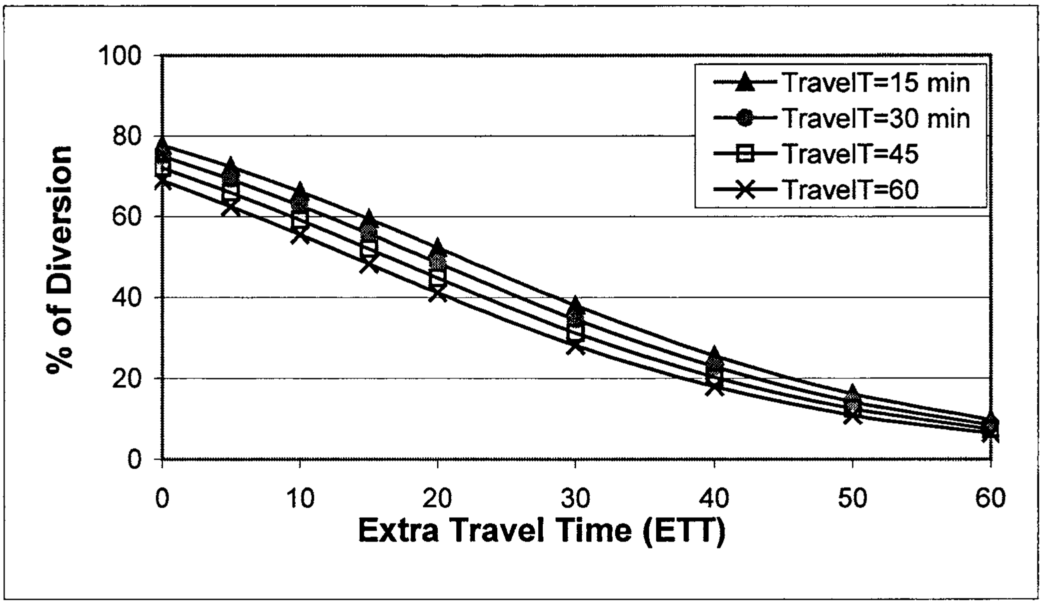


Figure 5.8 Effect of ETT and Trip Travel Time on the Probability of Diversion (Congestion- Delays)

Figure 5.9 shows that, the diversion rate due to the accident delays sign ranges from 72% to 62% for trip travel times between 15 and 60 minute when the travel time for both the usual and the alternative routes are the same. As the extra travel time increases, the diversion rate decreases until it reaches 7%-4% at ETT of 60 minute for trip travel times between 15 and 60 minute.

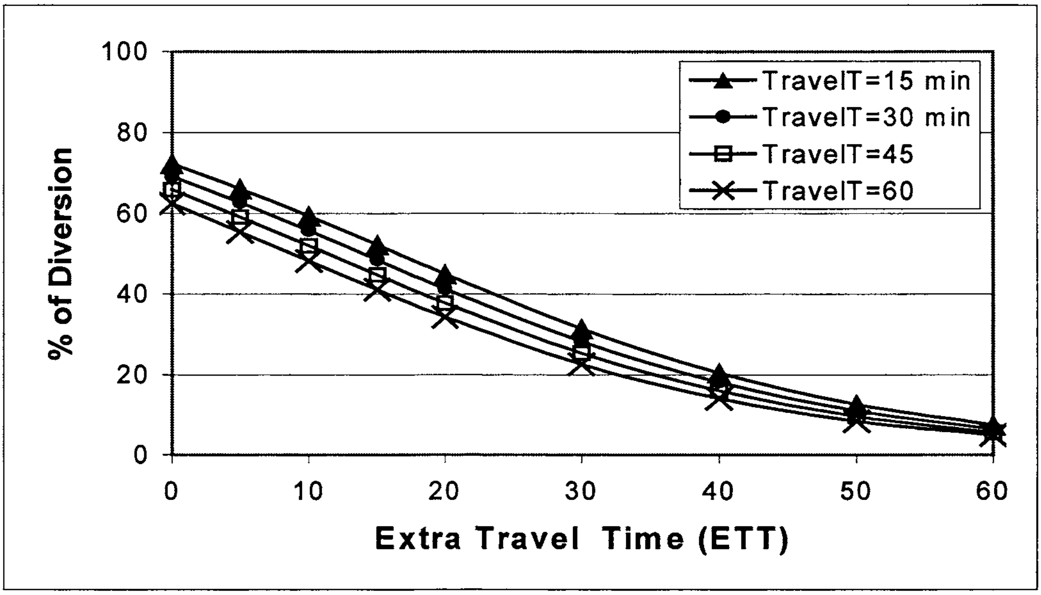


Figure 5.9 Effect of ETT and Trip Travel Time on the Probability of Diversion (Roadworks- Delays)

All the figures show that the probability of diversion decreases as the extra travel time, ETT, increases. Also, it decreases with the increase of trip travel time – trip length - regardless of the VMS content. That can be explained by the fact that, increasing the trip time decreases the "delay/trip time" ratio which means that the same amount of delay is more acceptable in a longer trip than is a shorter trip, and accordingly, the probability of diversion decreases. Furthermore, in the case of accident, the probability of diversion when the displayed severity is long delay is approximately the same as the 20-minute delay. In addition, the percent of diversion increases with the increase of the displayed delay time. The percent of diversion in the case of accident for ETT of 20 minutes for 10, 20, and 30 minute delay are about 46%, 64% and 78% for travel time of 30 minute. In this case, when the displayed delay on the usual route is equal to the extra travel time, ETT, (i.e., the travel time on the usual route including the incident delay equals the alternative route travel time) the probability of diversion is 64%. This high probability can be explained by the fact that the uncertainty of incidents decreases the drivers' willingness to use the usual route (where the incident occurs) and accordingly increases the probability of diversion.

5.3 The Effects of Familiarity with Alternative Route, Visible Queue and Willingness to Divert at Next Potential Diversion Points for Different VMS Information

Figure 5.10 shows that the percent of diversion for drivers using the alternative route a few times per week is higher than for those using it few times per month, which is nearly the same, about 10%, for those using it once a month. Also, drivers using the alternative route less than once per month divert with a rate less, by about 4%, than those using it once per month. These results are for different incident types and severity and for a driver who has trip time of 28.9 minute and extra travel time of 6.4 minute and does not face with visible queue and are willing to divert at next potential diversion points.

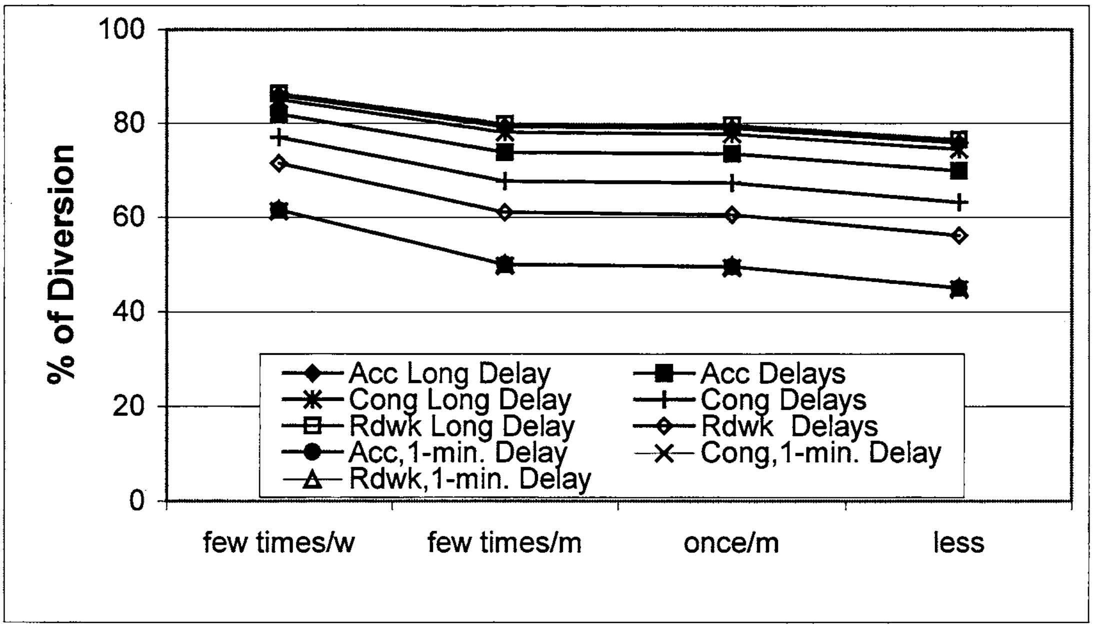


Figure 5.10 The Effect of the Familiarity with the Alternative Routes on the Probability of Diversion

When a queue is visible at the alternative route, the percent of diversion decreases by about 20% as shown in Figure 5.11. On the other hand, the percent of diversion increases by about 7% if the visible queue is on the usual route. These results are for different incident types and severity and for a driver who has trip time of 28.9 minute and extra travel time of 6.4 minute and using the alternative route few times per month and are willing to divert at next potential diversion points.

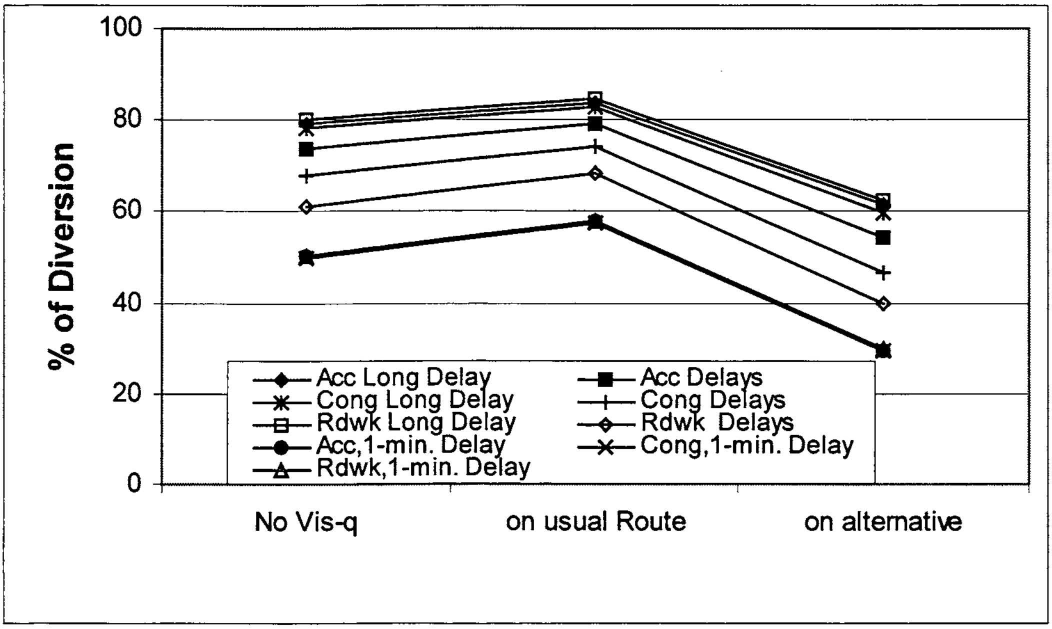


Figure 5.11 The Effect of the Existence of Visible Queue on the Probability of Diversion

Figure 5.12 shows that willingness to divert at next potential diversion points increases the percent of diversion by about 10% for different incident types and severity. This is for a driver who has trip time of 28.9 minute and extra travel time of 6.4 minute and using the alternative route few times per month and does not face with visible queue.

Analysing the effect of the familiarity with alternative route, the visible queue and the willing for diversion at next diversion points from Figure 5.10, Figure 5.11, Figure 5.12 show that, the percent of diversion is nearly the same for accident, roadworks, and congestion when the displayed severity is long delay. Also, the diversion rate is approximately constant for accident, roadworks, and congestion when the displayed severity is in minutes. On the other hand, the percent of diversion for accident delay is more than that for congestion delay which is more than for roadworks delay. These results are consistent with the results obtained from the effect message content on the percent of diversion. The parametric analysis has shown that all the effects between the probability of diversion and various explanatory variables can be logically explained and are consistent with the expected results.

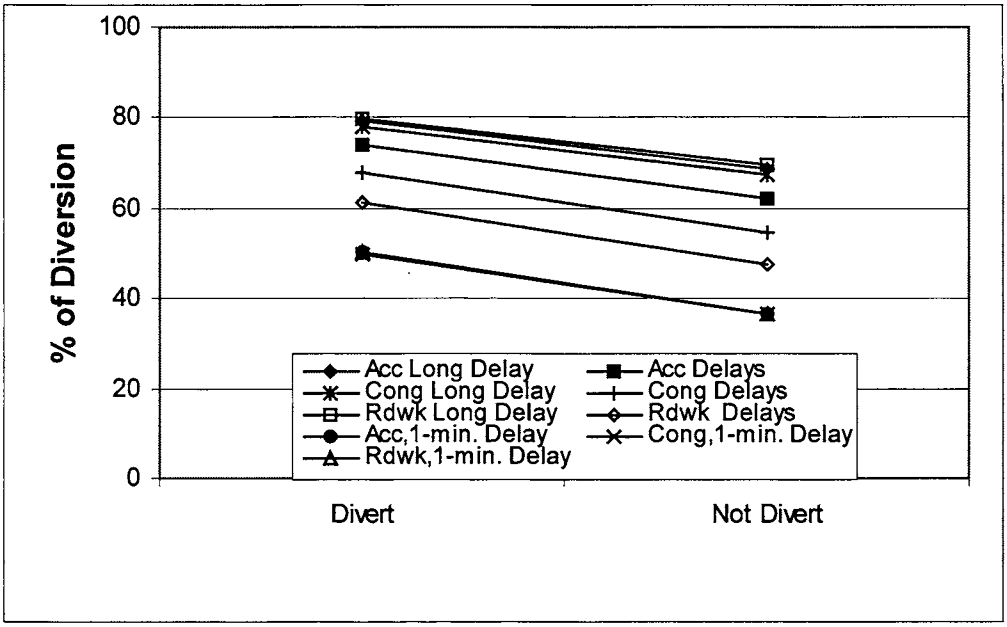


Figure 5.12 The Effect of Drivers' Willingness of Diversion at Next Potential Diversion Points on the Probability of Diversion

5.4 Comparison of the Developed Sydney VMS Model with Wardman's Model

Wardman *et al.* (1997) used a multinomial logit model to calculate the probability of diversion in the presence of VMS information. This model was calibrated based on data collected from a stated preference survey for the driver response to a wide range of VMS messages for a trip between Warrington and Manchester city centre in UK. In this survey each driver had to choose the route he/she would use out of three alternative routes as well as the usual route (ie., the choice set contains four different routes leading to the same destination) when seeing a VMS displaying information

The following paragraph to be added after the equation: **$U_{ij} = f(a_jX_{ij}, b_iS_i)$** ***in page 102***

The variables used in the model include different combinations of the displayed delay and its causes. The displayed delays are: delay time in minutes (Mins), likely delay (likely), and Long delays (Long). The delay causes are: roadworks (Road), congestion (Cong), accidents (Acc), and no reason given (None) (Wardman et al 1997).

about traffic conditions ahead. The form of the multinomial logit model is as follows:

$$P_{ij} = \frac{e^{U_{ij}}}{\sum_m e^{U_{im}}}$$

where

P_{ij} = the probability that driver i selects route j from the choice set of m alternatives

U_{ij} = the utility of alternative j for individual i

The utility of an alternative j is related to the relevant variables, which represent individuals' travel situations, X_j, and socio-economic characteristics, S_i:

$U_{ij} = f(a_j X_{ij},\ b_i S_i)$

The multinomial logit model coefficients which were obtained from the calibration process are shown in Table 5.1. The last three rows in Table 5.1 represent the three alternative route specific constants. In addition, the last column represents the incremental effect, which should be added to the base effect if the driver is in certain category.

The drivers normally consider one alternative route only (Khattak et al 1991). Thus, for the purpose of comparison, only one alternative route was considered in calculating the probability of diversion from Wardman's model. The probability of diversion resulting from Wardman's model was compared with that resulting from the VMS models using the same driver and trip characteristics.

The probabilities of diversion for both Wardman's and the developed Sydney VMS model were calculated for a trip of 29 minutes travel time, an extra travel time of 6 min, and for drivers who are willing to divert at next diversion point, and use the alternative routes few times a month. The results are shown in Figure 5.13 and Figure 5.14.

Figure 5.13 shows that the difference in the probability of diversion between Wardman Model and the Sydney VMS model is large, about 40%, for delay of 5 minutes. As the delay increases, the difference in the probability decreases until reaches 0, 2, and 8% for accident, congestion, and roadworks when the delay time equals 30 minutes. Also, it is clear that the probability of diversion of the Sydney VMS model is higher than that of Wardman model.

Table 5.1 Wradman's Model (Wardman *et al.* 1997)

	Base	Incremental
Road-Mins	-0.041	Age < 35 0.0043 Female 0.0040
Cong-Mins	-0.042	
Acc-Mins	-0.048	
None-Mins	-0.036	
Road-Likely	-0.595	
Cong-Likely	-1.876	
Acc-Likely	-2.1	
None-Likely	-0.835	
Road-Long	-2.732	
Cong-Long	-2.45	
Acc-Long	-3.337	
None-Long	-2.623	
Clear	0.815	
Vis-Q	-0.043	Age < 35 0.0129 Freq < 6 0.0145 Unreliable VMS -0.0133
Time	-0.068	
RSCM56	-1.489	Never use M56 -0.5440
RSCA580	-1.328	Never use A580 -0.9590
RSCA57	-1.47	Never use A57 -1.0420

Figure 5.14 shows that the probability of diversion resulting from Wardman model is less than that resulting from the Sydney VMS model when the displayed severity is delays for all incident types. Furthermore, the biggest difference in the probability of diversion, 40%, resulted when the incident type is roadworks, while a difference of about 19% resulted for both accident and congestion. In addition, the probability of

diversion for both models is nearly the same when the displayed severity is long delay for accident. On the other hand, in case of long delay, the probability of diversion resulting from Wardman model is less than that resulting from the VMS developed model for both roadworks and Congestion by 10% and 15%.

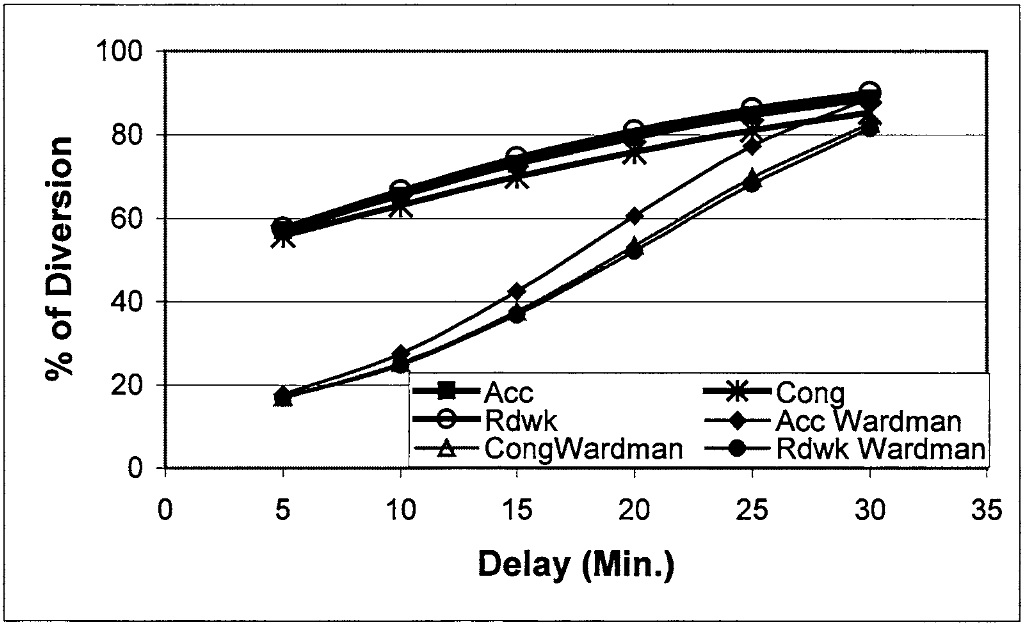


Figure 5.13 The Probability of Diversion for Both Wardman Model and the Developed VMS Model for Different Delay Times and Incident Types

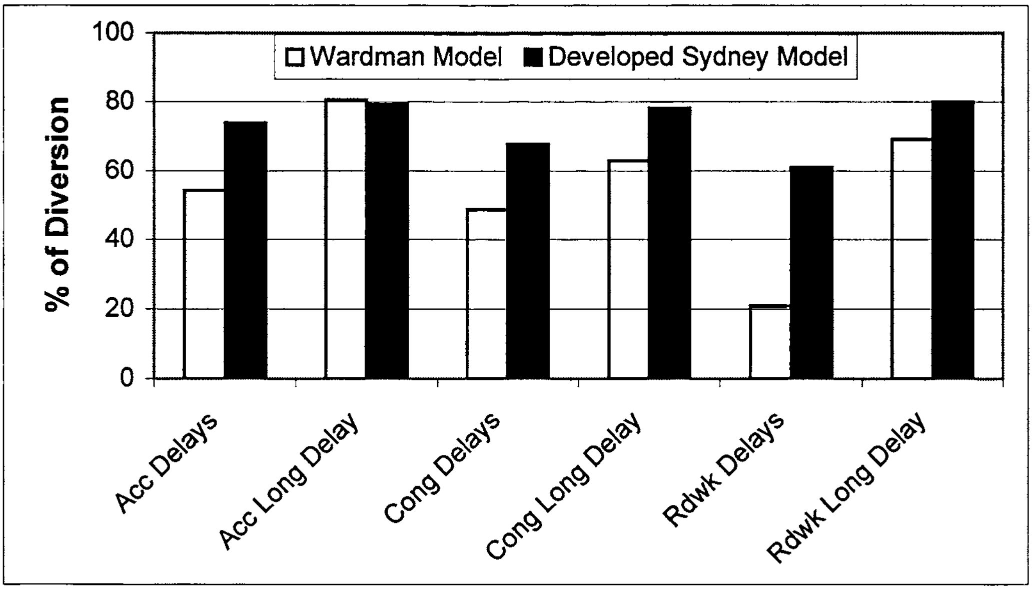


Figure 5.14 The Probability of Diversion for Both Wardman Model and the Developed VMS Model for Qualitative Delay and Different Incident Types

The predicted probability of diversion from the developed VMS model is significantly different from Wardman's model, which was developed in UK. While it is reasonable to assume that driver behaviour may be significantly different in Sydney than in the UK, this large difference may also be caused – at least partially – by the well-known weakness of a stated preference survey used for data collection in this study: that the responses to a questionnaire survey may be significantly different from the true decisions made by the same people in a real incident situation. The extent of this effect could be measured from field surveys conducted at existing VMS sites during incident conditions. While such a survey is beyond the scope of this study, we recommend that further research should be conducted to verify the validity of the developed model.

CHAPTER 6
IMPLEMENTATION AND VERIFICATION OF THE DEVELOPED MODEL IN SITRAS

6.1 INTRODUCTION

The VMS-response prediction model developed and presented in the previous chapters is able to predict the probability of diversion of individual drivers in response to different VMS contents, based on a number of driver and trip attributes. However, the overall effect of the VMS on the network performance can only be estimated by predicting the route choice behaviour of every driver passing the VMS site. Thus, the developed route diversion model was incorporated into a microscopic simulation model, called SITRAS, to explore the effect of VMS on network performance. Accordingly, SITRAS will be able to explore the VMS impacts on network and hence the benefits of using the variable message signs as an incident management tool can be evaluated. This chapter describes the SITRAS simulation model, the implementation of the VMS model into SITRAS, and verification of the VMS model implemented in SITRAS.

6.2 THE SITRAS SIMULATION MODEL

SITRAS (Simulation of Intelligent TRAnsport Systems) was developed at the University of New South Wales to provide an evaluation tool for Intelligent Transport Systems applications such as congestion and incident management, public transport priority and dynamic route guidance (Hidas 2001; Hidas & Behbahanizadeh 1999).

SITRAS is a microscopic time interval update simulation model in which vehicles are generated and moved through the network on an individual basis and the status of each vehicle object in the model is updated once in every one-second interval.

Figure 6.1 shows the overall model framework. The main modules of the model are: (a) route building based on the network data; (b) vehicle generation, using a random process from a negative exponential distribution, according to the given flow rate, demand distribution of trip destinations and vehicle composition; (c) vehicle progression, based on car following and lane changing theory; and (d) route selection, based on individual driver characteristics (Hidas & Behbahanizadeh 1999).

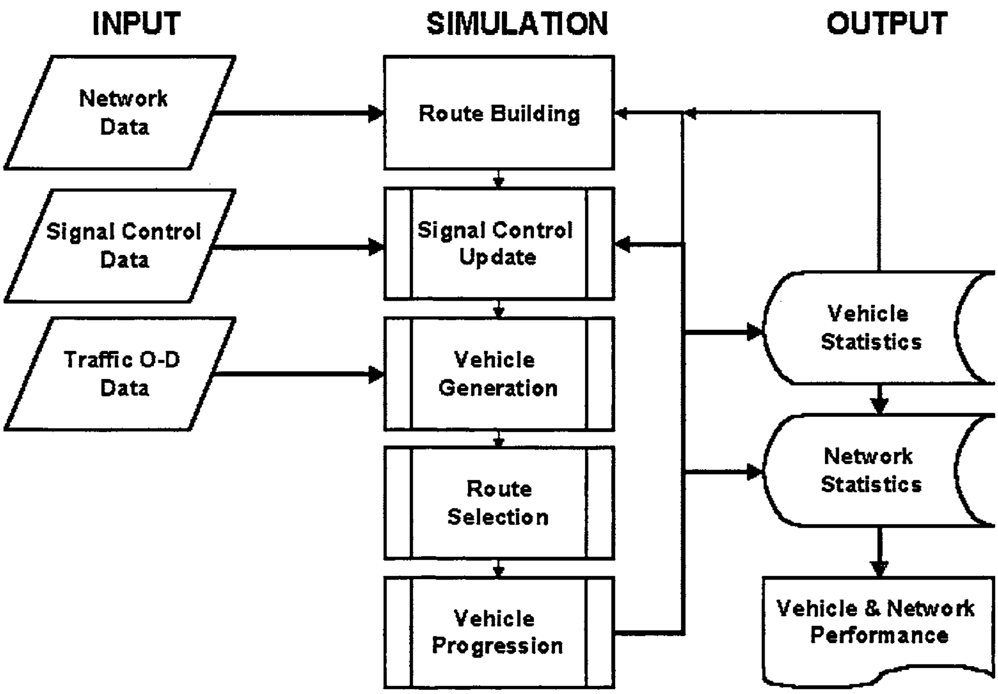


Figure 6.1 Flow Diagram of the Model Structure (Hidas & Behbahanizadeh 1999)

The vehicle objects travel between their user-defined origin and destination, selecting their route according to the prevailing traffic conditions and their individual route choice characteristics. Incidents varying in severity, location, time and duration can be programmed to occur on the network.

SITRAS simulation model consists of four main models: the network model, the control model, the traffic flow demand model and the vehicle model. The Network model represents the physical features of the road network, including the intersections and road links. The road network is represented in SITRAS by a set of nodes and links. Nodes represent intersections and freeway junctions, while links represent roads. The control model represents the traffic control characteristics of the network, such as traffic signal controls, and loop detectors. The traffic flow demand model specifies the input flow rates and composition and distribution characteristics for each source (Origin) point. The vehicle model represents the physical characteristics of vehicle types and the individual characteristics of the drivers (Hidas 2001; Hidas & Behbahanizadeh 1999).

SITRAS has the ability to model different type of nodes. These types include:

- Origin or Generator node: These are nodes from which vehicles enter the network. Each Origin node has a 'Generator' which generates vehicles according to the specified hourly flow rates,
- Destination: These are nodes at which vehicles can end their journey through the network,
- Origin-Destination: This special node type encapsulates features of 'Origin' and 'Destination' described above. The presence of this special node type eliminates the need to define two separate nodes at the same coordinates to act as both an origin and a destination,
- Signalised: This signifies that the node is to represent a signalised intersection. Several different signal control types (fixed time, adaptive and SCATS) can be used in a signalised node,
- Unsignalised: This type represents an unsignalised intersection, controlled by a STOP or GIVE WAY sign, or the general 'give way to the right' rule,
- Roundabout: This type represents a roundabout intersection,
- Merge: This specifies the node as a freeway merge point. At this node vehicles may enter the freeway from a ramp, and
- Diverge: This specifies the node as a freeway diverge point. At this node vehicles may leave the freeway to move onto a ramp (Hidas 2001; Hidas & Behbahanizadeh 1999).

The model can handle variable flow rates in order to study the dynamic effects of increasing or decreasing demand patterns. Also, it allows the simulation of unguided and guided vehicles. For unguided vehicles, drivers' imperfect knowledge of the prevailing network conditions was modelled according to Burrell's (1968)simulation method in which drivers perceived minimum cost of the route that they follow includes an error term distributed uniformly around the prevailing true cost with a spread factor. All guided vehicles, (ie. vehicles fitted with an in-vehicle route guidance system), were assumed to follow the given route advice based on the prevailing minimum cost routes (Hidas 2001; Hidas & Behbahanizadeh 1999).

SITRAS has the ability for modelling different traffic signal controls such as fixed-time signal co-ordination, adaptive signal control strategies, and SCATS-controlled signalised intersection. SCATS (Sydney Coordinated Adaptive Traffic System), which is a traffic signal control system, adjusts signal timing for each traffic movement automatically based on current traffic conditions. To model SCATS-controlled signalised intersections in SITRAS, the simulations must be run with SITRAS connected to SCATS software (which models SCATS signal control) through PC-TRAFF simulator developed by the RTA, all 3 programs running on the same computer. The SCATS signal control in SITRAS represents the physical elements of the signalised intersection and communicates with SCATS by providing detector occupancy data required by SCATS and by interpreting and executing signal group commands received from SCATS (Hidas 2001; Hidas & Behbahanizadeh 1999).

SITRAS also models the behavioural characteristics for different drivers through the following parameters:

- Driver Type: this is a positive integer in the range 0-99. This parameter represents how aggressive a driver is. A value of 50 represents the 'average driver'; a value less than 50 represents less aggressive, while a value above 50 represents more aggressive drivers. Driver type is automatically assigned by SITRAS, drawn from a normal distribution when the vehicle is created. This parameter is used to calculate most physical characteristics of the vehicle, such as speed, acceleration, gap acceptance and desired spacing, in a stochastic manner.

- Network Knowledge: represents the driver's familiarity with the network and it contains three levels. This parameter is used by unguided vehicles in the route selection process

6.3 IMPLEMENTATION OF THE VMS MODEL INTO SITRAS

The variables affecting the driver response to VMS information in the developed model are: the message content, the extra travel time under normal conditions, the normal trip length, the visible queue, the drivers' familiarity with the alternative routes, and the drivers willing for diversion at next potential diversion points.

In the developed prediction model, the drivers' familiarity with alternative routes variable consists of four categories, while SITRAS uses three categories. Thus, a slight modification was carried out in the developed VMS model to be consistent with the parameters already defined in SITRAS. This modification included merging two categories into one category. The two categories: few times per month and once a month were chosen to be merged into one category since their effect on the probability of diversion is nearly the same as their coefficients are –0.47 and –0.49 and as concluded in the parametric analysis chapter. The form of the VMS model, which was included into SITRAS, is as follows:

$$P = \frac{1}{1 + \exp^{(-U)}}$$

U= MessageContent - 0.058*ETT - 0.01* TT + V + D + W + 1.07

where

P = Probability of diversion,

U = The relative utility of the alternative route,

MessageContent = see Figure 6.2 for parameter values,

ETT = Extra travel time under normal conditions,

TT = Trip length under normal conditions,

V = Existence of visible queue, see Figure 6.2 for parameter values,

D = Drivers' familiarity with the alternative routes, see Figure 6.2 for parameter values,

W = Willingness to divert at next potential diversion points

= -0.55 if No

= 0.0 if Yes

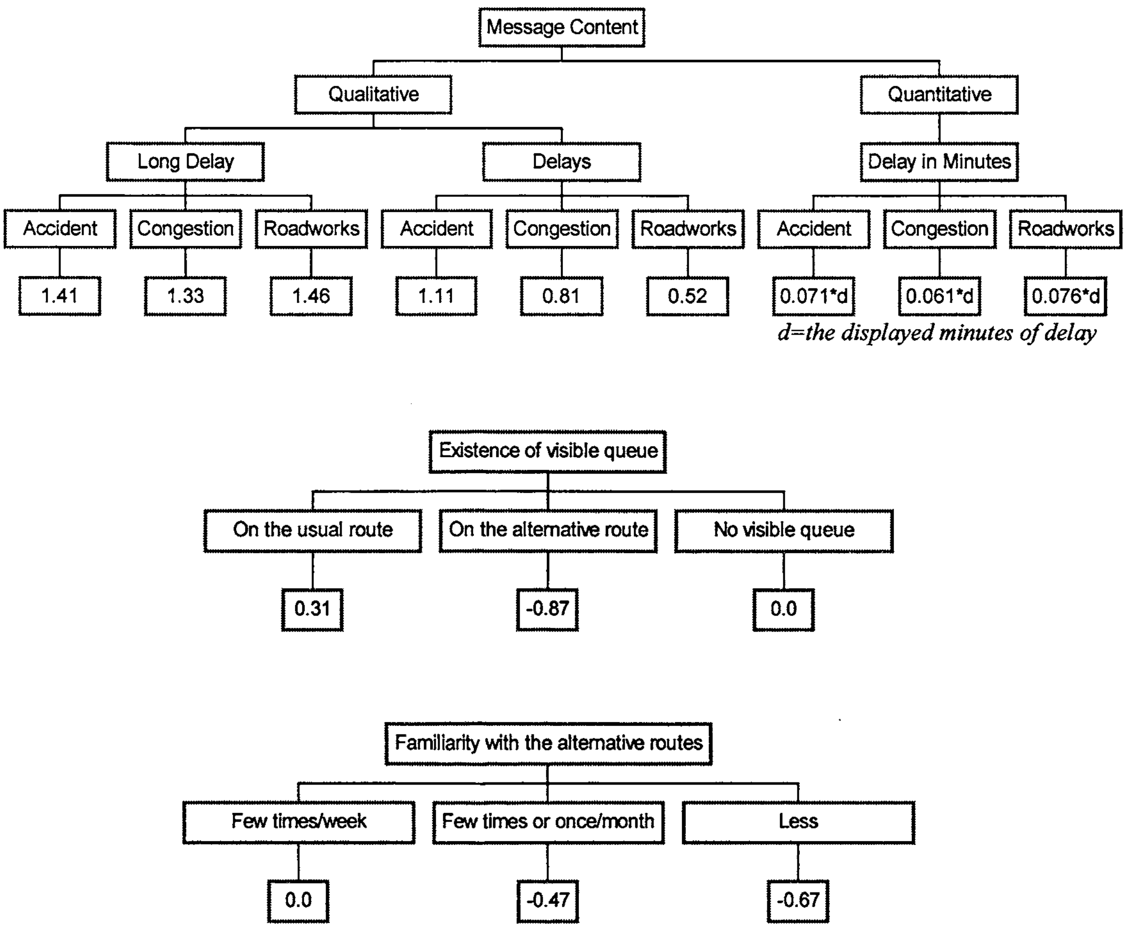


Figure 6.2 Parameter Values of the VMS Model Included in SITRAS

The willingness to divert at next diversion points variable can be considered in SITRAS by the driver aggressivity parameter: more aggressive drivers are more willing to divert at next diversion point than the less aggressive ones.

As shown in the VMS model, the message content has two main parts: incident type and severity. The incident type has three components: accident, congestion, and roadworks, while incident severity includes long delay and delays as a qualitative delay and quantitative delay represented in minutes of delay.

The following parameters were defined in SITRAS to represent the VMS content and location:

- Cause: a category indicating the incident type which includes: Accident, Congestion, and Roadworks.
- Severity: a category indicating the incident severity which includes: Long delay, Delays, Delay in minutes.
- Delay: the quantity of delay when severity is Delay in minutes
- Link: the Link which the VMS is located at
- Position: the distance from the end of the Link where the VMS is located
- Visibility: the distance within which drivers on the Link may see the message
- Affected Links: a list containing references to links which are affected by the Message: first is the link immediately after the VMS site, last is the link of the incident site reported in the Message.

The process of drivers' response to VMS message is executed in SITRAS through the following steps:

(a) Check if there is a Message currently displayed.

(b) If there is a Message that may affect drivers route choice, then a search is carried out for vehicles upstream of VMS location up to Visibility and the relevant parameter are passed to each vehicle found. The relevant parameters include cause, severity, delay and affected links.

(c) Based on the passed parameters to each vehicle, the existence of visible queue and the driver and trip characteristics, the probability of diversion is calculated for each vehicle. Drivers' characteristics include the familiarity with the alternative routes and the willingness to divert at next potential diversion point. The trip characteristics include the extra travel time under normal conditions, and the normal trip time.

(d) If there are more than one alternative links, the one with the highest probability of diversion is selected

(e) A random number from a uniform distribution in the range of 0 to 1 is generated.

(f) Vehicle decides to divert if the random number is in the range of 0 to the probability of diversion for that vehicle, otherwise vehicle decides not to divert and continue its route previously selected assuming normal traffic conditions.

6.4 VERIFICATION OF THE MODEL IMPLEMENTED IN SITRAS

The purpose of this section is to verify the VMS model implemented in SITRAS through two steps: first, verify the probability of diversion for each individual vehicle calculated in SITRAS, and second, compare the actual diversion rate for all vehicles with the estimated probability of diversion.

A simple hypothetical network was designed for the verification process. The network has one origin, node 900, and two destinations, nodes 200, and 400, as well as five nodes representing unsignalized intersections. Also, it contains seven one-way links and one two-way link as shown in Figure 6.3. The one way links are: link 900-600, 600-700, 700-400, 600-800, 800-500, 500-100 and 100-200. Vehicles travelling from the origin - node 900 - to destination 400 pass the links: 900-600, 600-700, and 700-400, while other vehicles travelling – from the origin - to destination 200 pass links: 900-600, 600-700, 700-100, and 100-400. A VMS was introduced at link 900-600 displaying delay information concerning link 600-700. All vehicles passing the VMS location – travelling from the origin to either destination 400 or 200 - have an alternative route they can divert to.

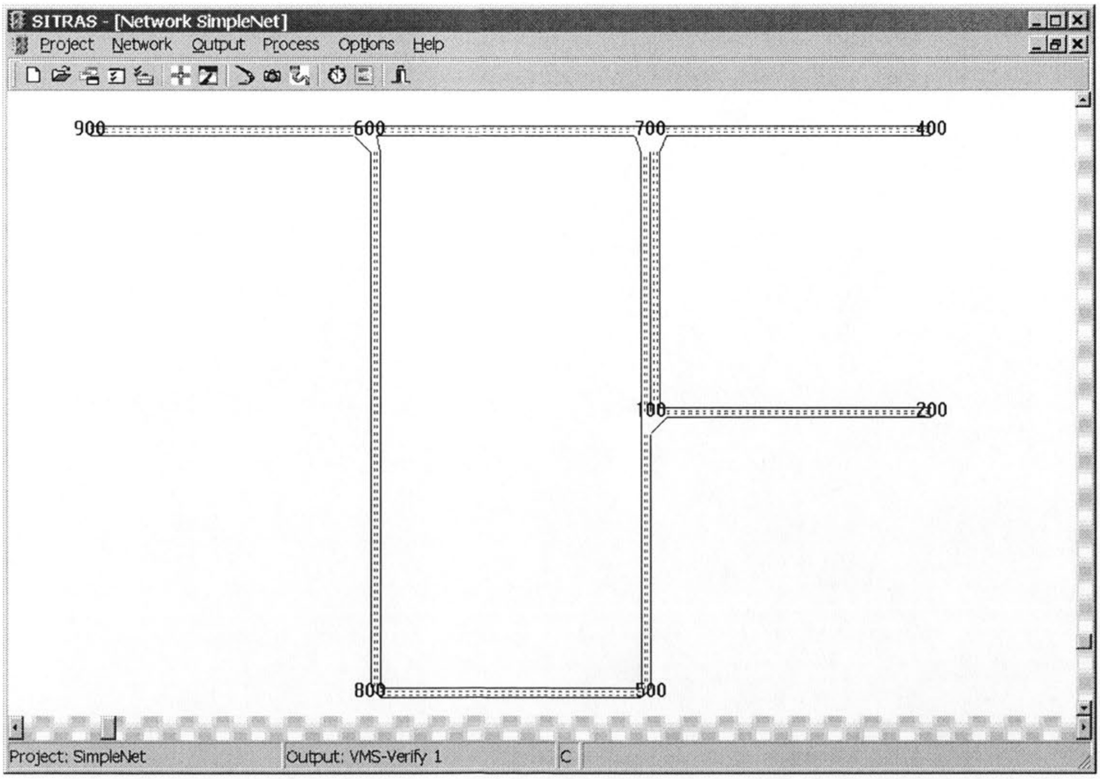


Figure 6.3 The Designed Network for Verifying the VMS Effect in SITRAS

The verification process included two parts. The first is verifying the calculated probability of diversion, in SITRAS, for each group of vehicles having the same parameters with respect to the estimated probability from the VMS model. The VMS model estimates the probability of diversion for individual vehicles depending on the VMS content, and the drivers and trip characteristics. If more than one vehicle have the same parameters, the probability of diversion of that group of vehicles is the same as that for one vehicle. The second concerns with verifying the ratio between the actual number of diverted and total vehicles, with respect to the probability of diversion, for each destination and for total flow. The probability of diversion for a destination can be obtained as the weighted average of the probability of diversion for all the groups of vehicles, having the same parameters, related to that destination. In addition, the probability of diversion for the total flow can be obtained as the weighted average of the probability of diversion for all the groups of vehicles. The weighted average of the probability of diversion is calculated as follows:

$$Weighted\ Average\ \Pr obability = \frac{\sum n_i * p_i}{\sum n_i}$$

where,

P_i = probability of diversion for each group of vehicles having the same parameters,

n_i = number of vehicles within each group of vehicles having the same parameters.

A total of 5 runs of SITRAS were carried out for the verification process. Each run was made using a specified VMS massage displayed at link 900-600. These messages are: accident long delay, accident delay, roadworks long delay, congestion delays, accident 5 minutes delay and congestion 10 minutes delay. Table 6.1 shows a summary of the results obtained from these runs as well as the weighted average probability, obtained from the VMS model, for each destination and for the total flow.

During the verification process, the probability of diversion for each individual vehicle calculated in SITRAS was printed out and compared with the probability of diversion estimated from the VMS model. The results show that the calculated probability for each vehicle in SITRAS is exactly the same as the estimated probability from the VMS model. In addition, Table 6.1 shows that the difference between the actual and estimated probability ranges between 0.03% and 4.2 %. These results indicate that the simulated effect of VMS response in SITRAS is close to the effect described by the VMS model. Thus, it can be concluded that the model implemented in SITRAS is a valid representation of the prediction model presented in previous chapters.

Table 6.1 Difference between the Actual Probability of Diversion Resulting from SITRAS and the Estimated Probability Resulting from the VMS Model

VMS Content	Destination	No. of cars	P* weighted (VMS-model)	Actual No.of diverted cars	P* Actual	Δ P**
Accident Long delay	200	222	88.8	189	85.1	3.7
	400	317	88.5	280	88.3	0.2
	ALL	539	88.7	469	87.0	1.7
Accident Delays	200	222	85.6	194	87.4	1.8
	400	317	85.2	269	84.9	0.3
	ALL	539	85.3	463	85.9	0.6
Roadworks Long delay	200	222	89.4	196	88.3	1.1
	400	317	89.0	277	87.4	1.6
	ALL	539	89.2	473	87.8	1.4
Congestion Delays	200	222	81.4	186	83.8	2.4
	400	317	81.0	270	85.2	4.2
	ALL	539	81.2	456	84.6	3.4
Accident 5 min. Delay	200	223	73.7	161	72.6	1.1
	400	317	73.1	235	74.1	1.0
	ALL	540	73.49	396	73.52	0.03
Congestion 10 min Delay	200	222	78.3	176	79.3	1.0
	400	317	77.8	239	75.4	2.4
	ALL	539	78.0	415	77.0	1.0

*Probability of diversion.

** Difference between the actual and the estimated probability of diversion.

CHAPTER 7
ASSESSMENT OF VMS BENEFITS:
M2 HILLS MOTORWAY CASE STUDY

7.1 INTRODUCTION

To assess the benefits of using VMS as an incident management tool, a part of Sydney Metropolitan Area road network was chosen. This part includes the western section of the new M2-Hills Motorway, which is bounded between Windsor Road and Old Windsor Road, and the arterial roads around it. This part will be called M2 network in the next sections. The assessment of VMS benefits was carried out through applying three sets of simulation. First, a simulation set was run without incident to obtain base performance indicators for the prevailing traffic conditions, called the base case. Second, a simulation set was run with an incident on the M2 motorway, using the same traffic control conditions as in the base case, called the incident case. Finally, a set of simulations was run with the same incident and with displaying VMS information at different locations to manage the incident, called the Incident management case. The results of these simulation sets were compared and the optimum incident management plan, which gives the maximum benefits of using VMS, was recommended. Also, the effect of increasing the flow rate of the incident link on the effectiveness of VMS, for the recommended incident management plan, was investigated.

7.2 SIMULATION DETAILS

To evaluate the effectiveness of VMS as an incident management tool in the M2 network, SITRAS was applied with the following input details:

- Simulation period: the total simulation period was 3.5 hours covering the morning peak from 6:30 to 10:00 am. The first 15-30 minutes are used as a 'warm-up' period during which the network is gradually filled in with vehicles.

- Number of simulation runs: as SITRAS is a stochastic simulation model, the output results depend on the selected random number seed. Therefore, five simulation runs were made using different random seeds and the mean of the results was calculated to produce a set of average performance measures. These five simulation runs will be called one group of runs, and we will deal directly with the mean of their results in the next sections.

- SCATS data for field signal control: the simulations were run with SITRAS connected to SCATS (which models SCATS signal control) through PC-TRAFF, all 3 programs running on the same computer.

7.3 INPUT DATA FOR M2 NETWORK

7.3.1 M2 Network Data

The M2 network includes 3 road corridors in an roughly East/West direction: the Western section of the M2 Hills motorway between Windsor Road and Old Windsor Road, and two parallel arterials – Seven Hills Road and Caroline Chisholm Drive, and 2 North/South corridors: a section of Old Windsor Road and Windsor Road. The network is shown in Figure 7.1.

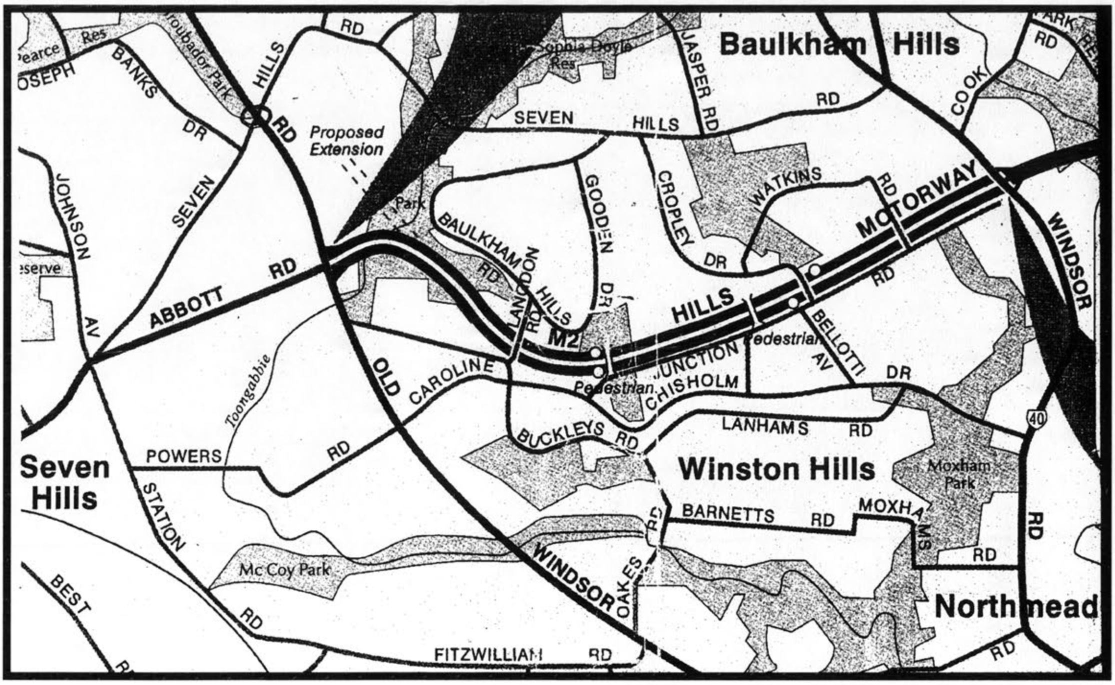


Figure 7.1 The M2 Network

As mentioned in the previous chapter, SITRAS treats roads as links and intersections and freeway junctions as nodes. Figure 7.2 shows the M2 network in SITRAS which comprises 76 links.

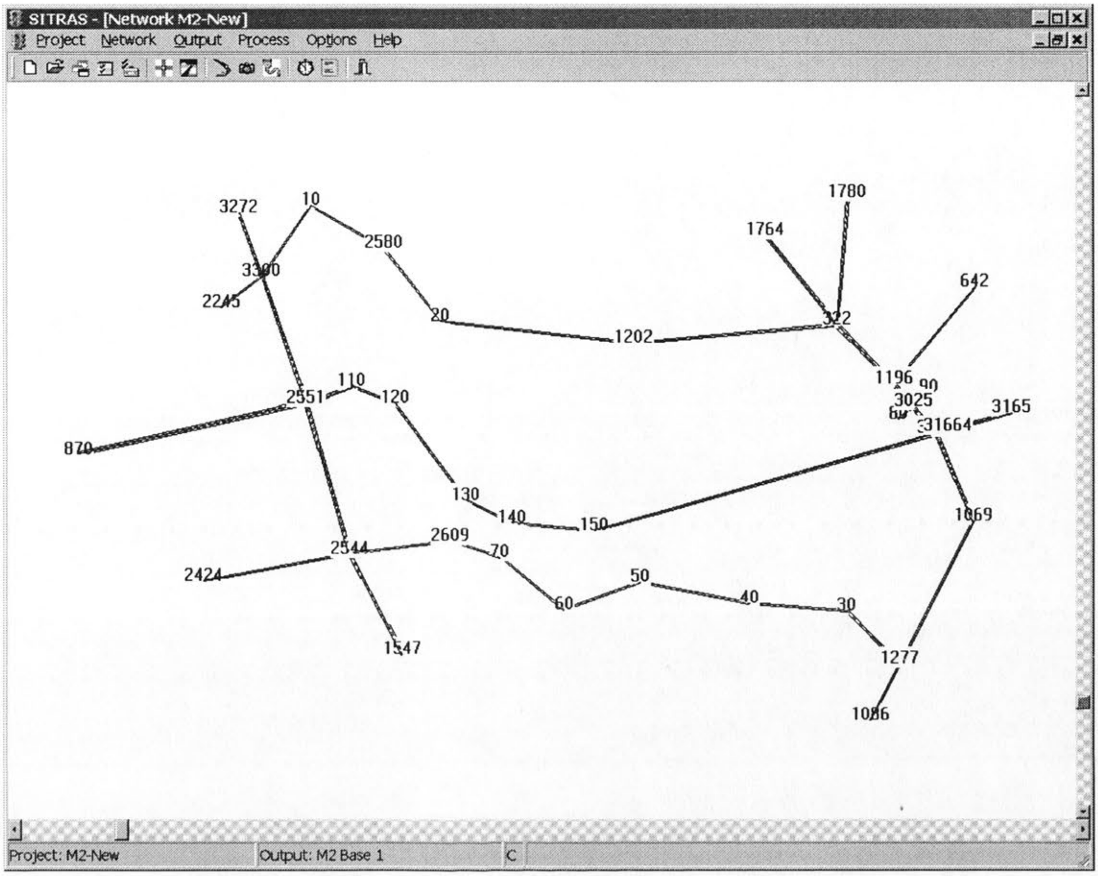


Figure 7.2 The M2 Network in SITRAS

Table 7.1 presents a list of the main nodes (intersections) of the network. There are 12 Origin-Destination nodes at the boundary of the study area where traffic flow enters and leaves the area. The simulated network includes 7 signalised intersections controlled by SCATS, a roundabout, which is also under temporary SCATS-control, and the on- and off-ramps of the M2 motorway at Windsor Road. The other nodes of the network model not shown in the table are 'virtual nodes', included only to provide a better representation of the network geometry.

Table 7.2 shows main input parameters of the links of the M2 network. The total number of links is 76 and the total length of links in the network is 46.26 km.

Table 7.1 Nodes of the M2 Network

Node ID	Node Type	Description
80	Origin-Destination	Torr St, Baulkham Hills
90	Origin-Destination	Oakland Ave, Baulkham Hills
642	Origin-Destination	Cook St, Baulkham Hills
870	Origin-Destination	Abbott Rd, Seven Hills
1086	Origin-Destination	Windsor Rd South, Northmead
1547	Origin-Destination	Old Windsor Rd South, Baulham Hills
1764	Origin-Destination	Windsor Rd North, Baulkham Hills
1780	Origin-Destination	Old Northern Road, Baulkham Hills
2245	Origin-Destination	Seven Hills Rd, Seven Hills
2424	Origin-Destination	Powers Rd, Seven Hills
3165	Origin-Destination	M2 East, Northmead
3272	Origin-Destination	Old Windsor Rd North, Seven Hills
322	SCATS-signal	Old Northern Rd, Seven Hills Rd, Windsor Rd - Baulkham Hills
1196	SCATS-signal	Windsor Rd, Cook St - Baulkham Hills
1277	SCATS-signal	Windsor Rd, Churchill Dr - Northmead
2544	SCATS-signal	Caroline Chisholm Dr, Old Windsor Rd, Power Rd - Baulkham Hills
2551	SCATS-signal	Abbott Rd, Old Northern Rd, M2 - Seven Hills
3025	SCATS-signal	Windsor Rd, Oakland Av & Torrs St - Baulkham Hills
3166	SCATS-signal	M2_E/B on ramp, M2 W/B off ramp, Windsor Rd - Baulkham Hills
3300	SCATS-roundabout	Old Windsor Rd, Seven Hills Rd - Seven Hills
31660	Merge	M2 Eastbound on ramp
31664	Diverge	M2 Westbound off ramp

Table 7.2 Link Data for the M2 Network

Link ID	Name	Length (m)	Speed (km/h)	Lane	Turn-Ctrl*
2245-3300	Seven Hills Rd Eastbound	238	60	2	
3300-10	Seven Hills Rd Eastbound	589	60	2	
10-2580	Seven Hills Rd Eastbound	506	60	2	
2580-20	Seven Hills Rd Eastbound	552	60	2	
20-1202	Seven Hills Rd Eastbound	1186	60	2	
1202-322	Seven Hills Rd Eastbound	1251	60	3	
322-1780	Old Northern Road N/E	772	60	2	
1780-322	Old Northern Road S/W	772	60	3	
322-1202	Seven Hills Rd Westbound	1251	60	2	
1202-20	Seven Hills Rd Westbound	1186	60	2	
20-2580	Seven Hills Rd Westbound	552	60	2	
2580-10	Seven Hills Rd Westbound	506	60	2	
10-3300	Seven Hills Rd Westbound	589	60	3	S
3300-2245	Seven Hills Rd Westbound	238	60	2	
870-2551	Abbott Rd Eastbound	1436	60	6	S
2551-110	M2 Motorway Eastbound	346	90	3	
110-120	M2 Motorway Eastbound	265	90	2	
120-130	M2 Motorway Eastbound	729	90	2	
130-140	M2 Motorway Eastbound	292	90	2	
140-150	M2 Motorway Eastbound	491	90	2	
150-31660	M2 Motorway Eastbound	2267	90	2	
31660-3165	M2 Motorway Eastbound	380	90	3	
3166-31660	M2 on-ramp Eastbound	76	60	2	
31664-3166	M2 off-ramp Westbound	63	60	3	S
3165-31664	M2 Motorway Westbound	379	90	3	
31664-150	M2 Motorway Westbound	2267	90	2	
150-140	M2 Motorway Westbound	491	90	2	
140-130	M2 Motorway Westbound	292	90	2	
130-120	M2 Motorway Westbound	729	90	2	
120-110	M2 Motorway Westbound	265	90	2	
110-2551	M2 Motorway Westbound	346	90	6	S
2551-870	Abbott Rd Westbound	1436	60	4	
2424-2544	Powers Rd Eastbound	908	60	3	S
2544-2609	Caroline Chisholm Dr Eastbound	720	60	2	
2609-70	Caroline Chisholm Dr Eastbound	299	60	2	
70-60	Caroline Chisholm Dr Eastbound	491	60	2	
60-50	Caroline Chisholm Dr Eastbound	478	60	2	
50-40	Caroline Chisholm Dr Eastbound	663	60	2	
40-30	Caroline Chisholm Dr Eastbound	584	60	2	
30-1277	Caroline Chisholm Dr Eastbound	443	60	2	
1277-30	Caroline Chisholm Dr Westbound	443	60	2	
30-40	Caroline Chisholm Dr Westbound	584	60	2	
40-50	Caroline Chisholm Dr Westbound	663	60	2	

Link ID	Name	Length (m)	Speed (km/h)	Lane	Turn-Ctrl*
50-60	Caroline Chisholm Dr Westbound	478	60	2	
60-70	Caroline Chisholm Dr Westbound	491	60	2	
70-2609	Caroline Chisholm Dr Westbound	299	60	2	
2609-2544	Caroline Chisholm Dr Westbound	720	60	3	
2544-2424	Powers Rd Westbound	908	60	3	
3272-3300	Old Windsor Rd Southbound	341	60	2	
3300-2551	Old Windsor Rd Southbound	800	60	5	R
2551-2544	Old Windsor Rd Southbound	1000	60	4	R
2544-1547	Old Windsor Rd Southbound	689	60	3	
1547-2544	Old Windsor Rd Northbound	689	60	4	SR
2544-2551	Old Windsor Rd Northbound	1000	60	5	S
2551-3300	Old Windsor Rd Northbound	800	60	4	
3300-3272	Old Windsor Rd Northbound	341	60	2	
1764-322	Windsor Rd Southbound	689	60	4	S
322-1196	Windsor Rd Southbound	407	60	3	
1196-3025	Windsor Rd Southbound	156	60	4	
3025-3166	Windsor Rd Southbound	212	60	4	S
3166-1069	Windsor Rd Southbound	566	60	3	
1069-1277	Windsor Rd Southbound	986	60	3	R
1277-1086	Windsor Rd Southbound	374	60	2	
1086-1277	Windsor Rd Northbound	374	60	2	
1277-1069	Windsor Rd Northbound	986	60	2	
1069-3166	Windsor Rd Northbound	566	60	4	R
3166-3025	Windsor Rd Northbound	213	60	4	R
3025-1196	Windsor Rd Northbound	155	60	4	R
1196-322	Windsor Rd Northbound	407	60	5	S
322-1764	Windsor Rd Northbound	689	60	2	
1196-642	Cook St Eastbound	762	60	2	
642-1196	Cook St Westbound	762	60	2	
80-3025	Torr St Eastbound	91	60	2	
3025-80	Torr St Westbound	91	60	1	
3025-90	Oakland Ave Eastbound	104	60	1	
90-3025	Oakland Ave Westbound	104	60	2	
* R: right-turn filtering, S: slip-lane					

7.3.2 Traffic Data

Traffic data for the M2 network includes the flow rates for the origin nodes. The variable flow rate data in 15-minute intervals is shown in Table 7.3.

Table 7.3 Traffic Flow Rates for the M2 Network (veh/h)

Origin Time	80	90	642	870	1086	1547	1764	1780	2245	2424	3165	3272
6:30	20	32	416	1556	984	540	1180	704	1248	200	440	1156
6:45	32	40	480	1544	1052	564	1340	720	1220	196	724	1196
7:00	16	52	484	1676	908	700	1496	1024	1252	192	744	1148
7:15	24	64	524	1732	1088	720	1564	824	1156	192	1004	1036
7:30	20	80	712	1944	1104	1264	1192	1036	1108	228	1216	1020
7:45	36	72	668	2020	1236	1300	1036	940	956	232	1296	1056
8:00	32	108	680	1860	1264	1304	924	992	904	284	1360	948
8:15	16	120	692	1996	1220	1336	1312	956	972	224	1364	988
8:30	24	184	688	1608	1220	1460	1100	1144	892	264	996	968
8:45	28	224	740	1324	1204	996	1404	912	976	316	1048	912
9:00	72	188	644	1064	1244	1068	1180	928	900	348	796	960
9:15	60	68	596	924	1268	948	1060	1156	840	284	860	1124
9:30	32	84	548	784	1216	876	940	924	784	308	796	1044
9:45	20	36	580	772	1192	920	844	884	776	264	692	916

7.3.2.1 Flow Distribution

Table 7.4 shows the distribution of the 15-minutes traffic flow rates between the different origins and destinations for the M2 network.

Table 7.4 Distribution of O-D Flows for the M2 Network (%)

To From	80	90	642	870	1086	1547	1764	1780	2245	2424	3165	3272
80	0	78.22	3.96	0.99	3.96	0.99	5.94	2.97	0	0	1.98	0.99
90	76.01	0	0	0	16.47	0	0	0	0	0	7.51	0
642	2.42	0.05	0	2.08	19.34	4.8	35.39	19.24	1.41	1.36	12.94	0.97
870	0.02	0.24	0.4	0	8.69	27.21	2.26	0.78	3.63	4.95	49.58	2.24
1086	0.03	5.66	6.02	4.37	0	16.1	24.89	13.29	2.53	11.66	13.83	1.63
1547	0.09	0.18	0.58	29.28	7.49	0	3.2	1.8	14.06	21.58	13.39	8.34
1764	7.51	0	21.48	0.05	50.09	0.56	0	0.96	0	0.44	18.86	0.05
1780	2.93	0.16	10.79	5.64	26.84	19.62	1.89	0	6.28	3.44	18.8	3.63
2245	0.65	0.06	2.78	4.89	8.87	12.28	12.62	8.35	0	1.79	8.69	39.02
2424	0.12	0.7	0.46	6.6	25.84	47.28	5.68	2.43	3.01	0	6.03	1.85
3165	0.06	3.24	3.03	33.36	25.78	9.02	12.05	6.51	3.39	1.71	0	1.83
3272	1.66	0.23	3.4	4.61	12.4	18.22	19.05	11.41	8.54	3.02	17.46	0

7.4 MEASURES OF PERFORMANCE

The benefits of using VMS on the network performance can be evaluated by comparing network performance measures for both cases of incident and incident management using VMS. Also, the effect of incidents on the network can be obtained by comparing the performance measures of the network under normal condition and with incident. The performance measure selected for evaluating incident effect and the VMS benefits on the overall network is the total travel time in vehicle hours. The total travel time is the total amount of time experienced by all vehicles in the network. Thus, it is a good indicative measure to compare network performance for the entire network. For evaluating the incident effect and the VMS benefits on different links of the network, the total link travel time, in veh-hr, and the average link speed, in km/hr, were chosen as appropriate measures of performance. The total link travel time is the total amount of time experienced by all vehicles passing that link.

7.5 M2 NETWORK PREVAILING TRAFFIC CONDITIONS (BASE CASE)

One group of runs, five simulation runs, was made for M2 network without incident to obtain base performance indicators for the prevailing traffic conditions. The average link flow and speed were calculated for the whole 3.5 hour simulation time.

Figure 7.3 shows the flow rate, in vehicles/hour, for each link, averaged over the whole simulation period. On the M2 motorway, the flow rate in the Eastbound direction is around 1,100 veh/h which increases to 1,700 veh/h after the Windsor Road on-ramp. In the Westbound direction of the M2 motorway the flow rate is about 500 veh/h. On both Old Windsor Road and Windsor Road the Southbound flow is the dominant flow, exceeding 1,400-1,800 veh/h, while the Northbound flow is below 1,000 veh/h.

Figure 7.4 shows the speed, in km/hour, for each link averaged over the whole simulation period. On the mid-block section of the M2 motorway, the average speed is close to the free-flow speed of 90 km/h in both directions. A slight decrease of mean speed is noticeable at the East end of the study area (links 31660-3165 and 3165-31664) due to the effects of on- and off-ramps to and from Windsor Road. At the West end, the effects of the signalised intersection with Old Windsor Road are stronger, especially in the Westbound direction: the mean speed in the Eastbound direction (link 2551-110) is around 70 km/h due to the low entry speeds, while in the Westbound direction (link 110-2551) the mean speed drops to around 25 km/h due to the stopped delay incurred at the traffic signal.

The two parallel arterials (Seven Hills Rd and Caroline Chisholm Dr) are close to their free-flow speeds. The average speed along Windsor Road is around 40 km/h Southbound and about 50 km/h Northbound. Very low mean speed (less than 10 km/h) is recorded at the North approach to the roundabout (link 3272-3300). Old Windsor Road in both directions has average speeds between 25-40 km/h to the North of the M2 motorway on-ramp, and close to 60 km/h to the South of the M2. The off-ramp from the M2 to Old Windsor Road also has a mean speed below 10 km/h (link 31664-3166).

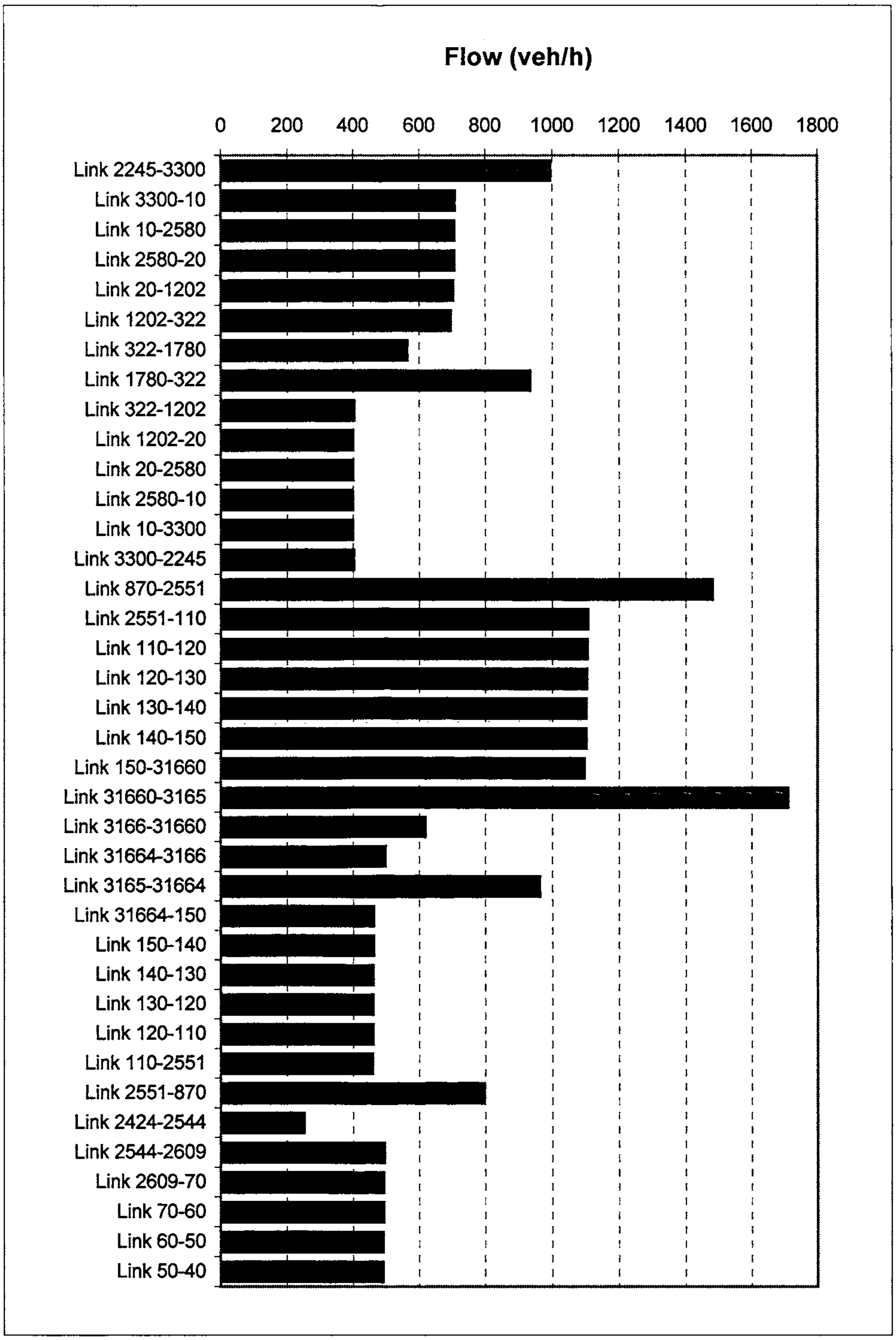


Figure 7.3 Average Link Flow Rate for the Whole Simulation Period (Base Case)

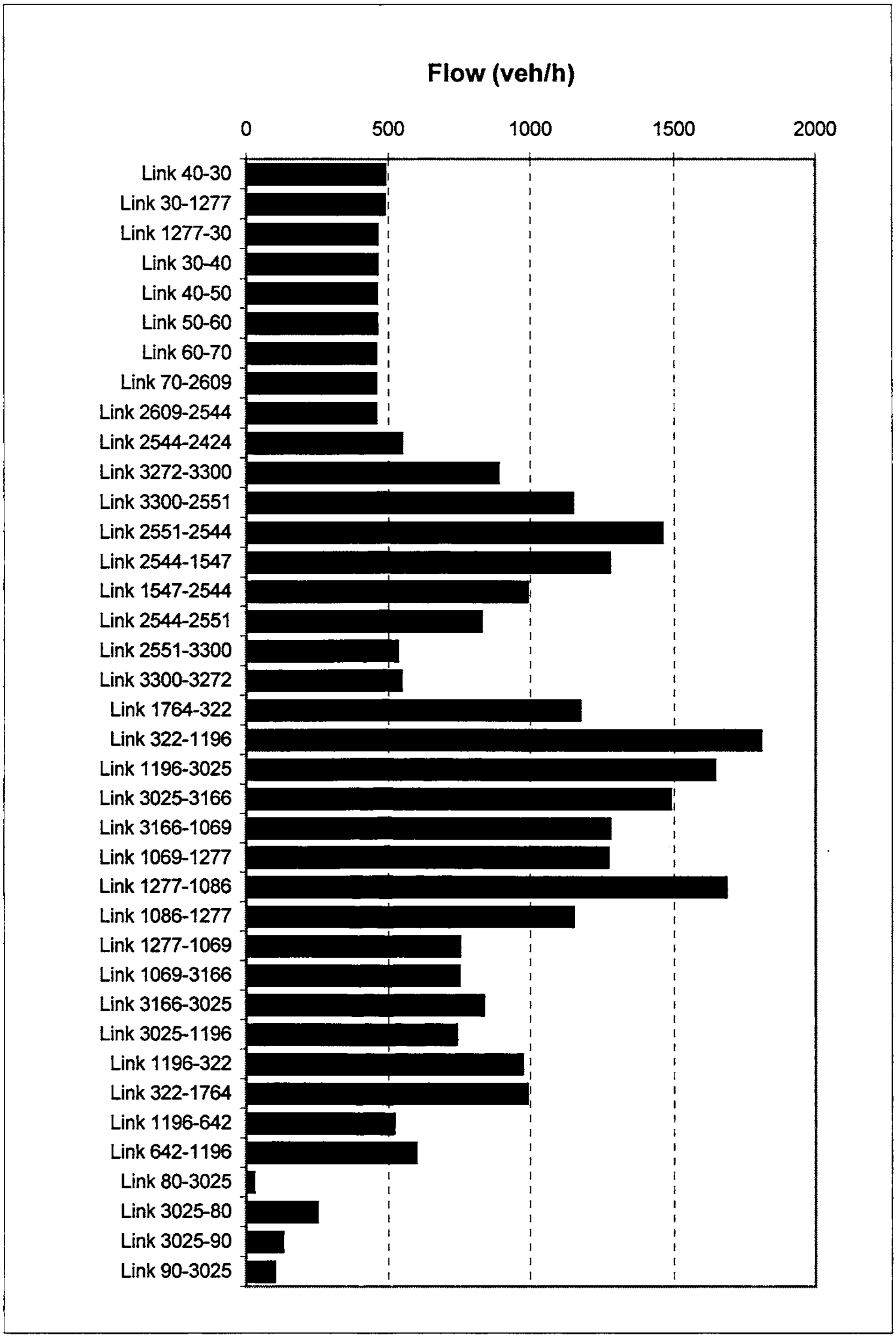


Figure 7.3 (cont.) Average Link Flow Rate for the Whole Simulation Period (Base Case)

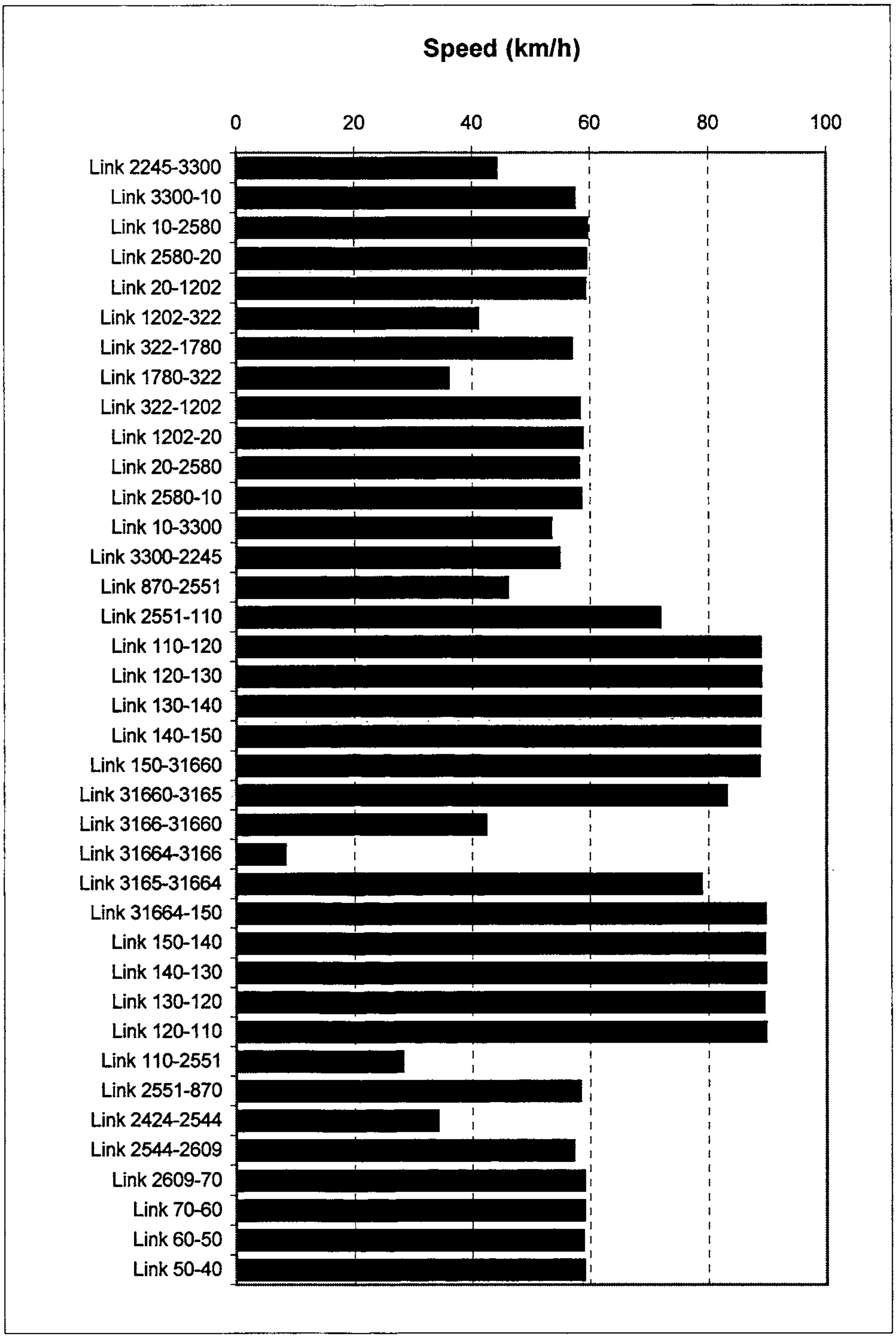


Figure 7.4 Average Link Speed for the Whole Simulation Period (Base Case)

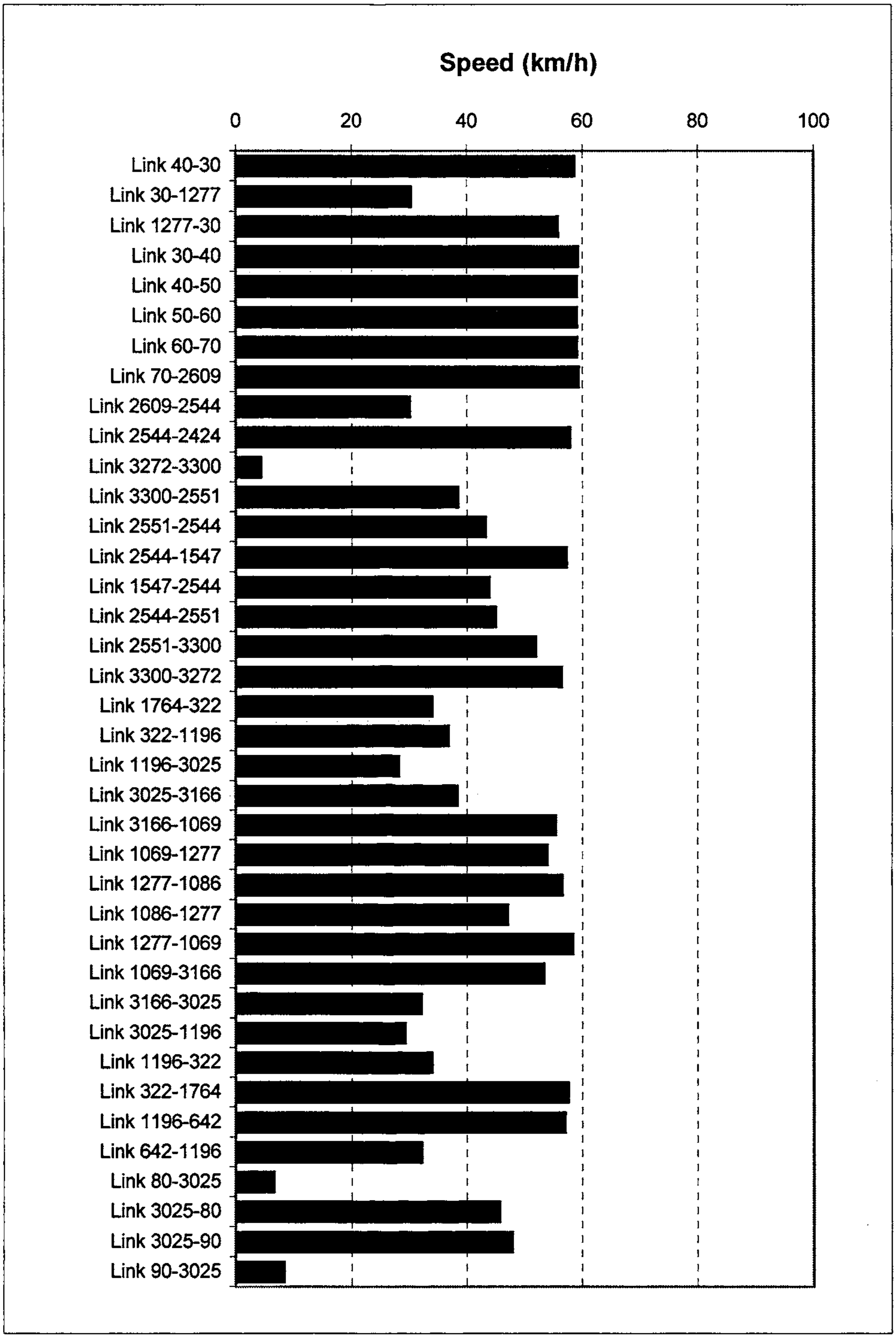


Figure 7.4 (cont.) Average Link Speed for the Whole Simulation Period (Base Case)

7.6 Effect of an Incident on the M2 Motorway (Incident Case)

An accident was introduced on the link 2551-110 of the M2 motorway. The accident blocked one lane out of two and was located close to the middle of the link. The accident duration was two hours from 7:00 to 9: am

One group of runs, five simulation runs, was made with the specified accident on the M2 motorway using the same traffic control conditions as in the base case. The average link speed and the total link travel time were calculated for the whole 3.5 hour simulation time. Also, the total network travel time was calculated for the whole simulation period by adding up the total travel time for all links. The results were compared with the base case.

It was found that, the total travel time for the whole network with accident is 2986 veh-hr compared to 2632 veh-hr in the base case. Accordingly, the accident resulted in 354 veh-hr increase in the network travel time.

Figure 7.5 shows the travel time, in veh-hour, for each link for the whole simulation period for both the base and incident cases. The accident increased the travel time on the accident link, 2551-110, more than four times from 19 to 87 veh-hr. In addition, the travel time increased from 162 to 383 veh-hr, more than twice, for link 870-2551 upstream the accident link. Also, for links 3300-2551 and 2544-2551, which are located upstream of the incident link, the travel time increased from 84 to 131 veh-hr and from 64 to 76 veh-hr respectively. The accident did not have any noticeable effect on the other links of the network. Accordingly, it can be concluded that the major effect of the accident is for the accident link, Abott Road and Old Windsor Road south bound. In addition some effect appears on the Old Windsor Road north bound.

Figure 7.6 shows the speed, in km/hour, for each link averaged over the whole simulation period for both the base and incident cases. The accident decreased the speed of the accident link, 2551-110, 57 km/hr from 72 to 15 km/hr. In addition, speed decreased from 46 to 20 km/hr, less than half, for link 870-2551. Also, for links 3300-2551 and 2544-2551, the speed decreased from 40 to 25 km/hr and from 45 to 39 km/hr.

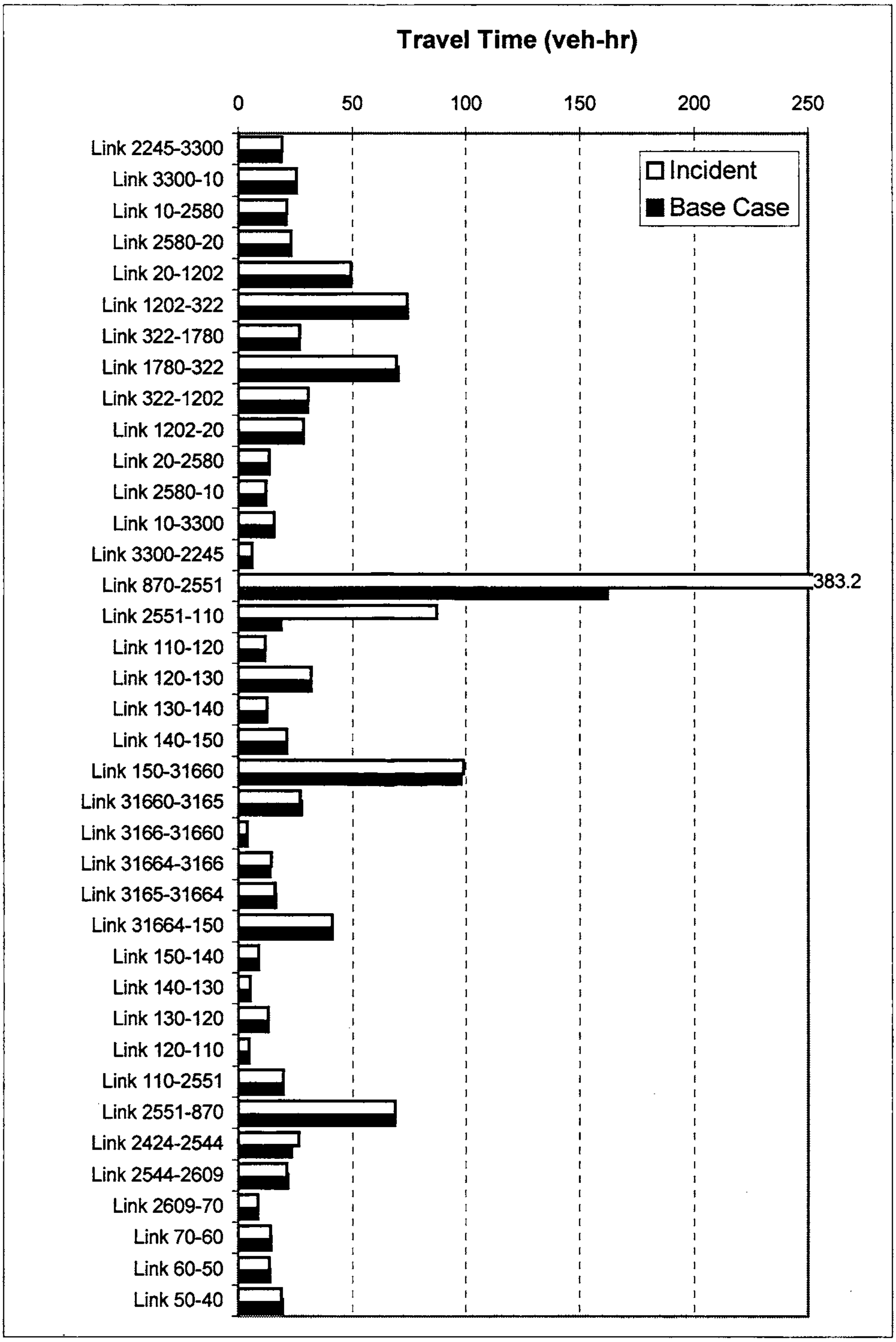


Figure 7.5 Total Link Travel Time for the Whole Simulation Period (Base & Incident Cases)

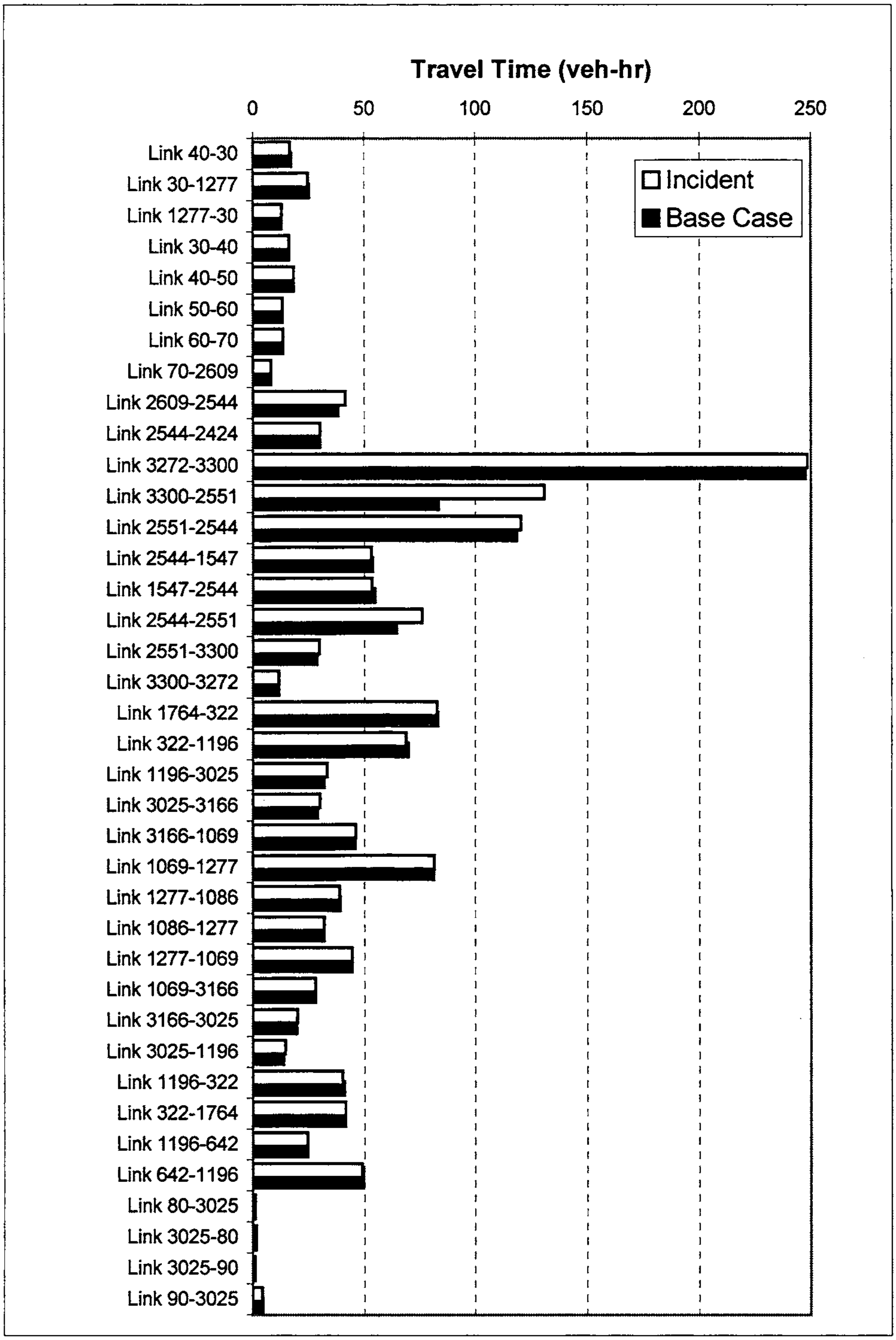


Figure 7.5 (cont.) Total Link Travel Time for the Whole Simulation Period (Base & Incident Cases)

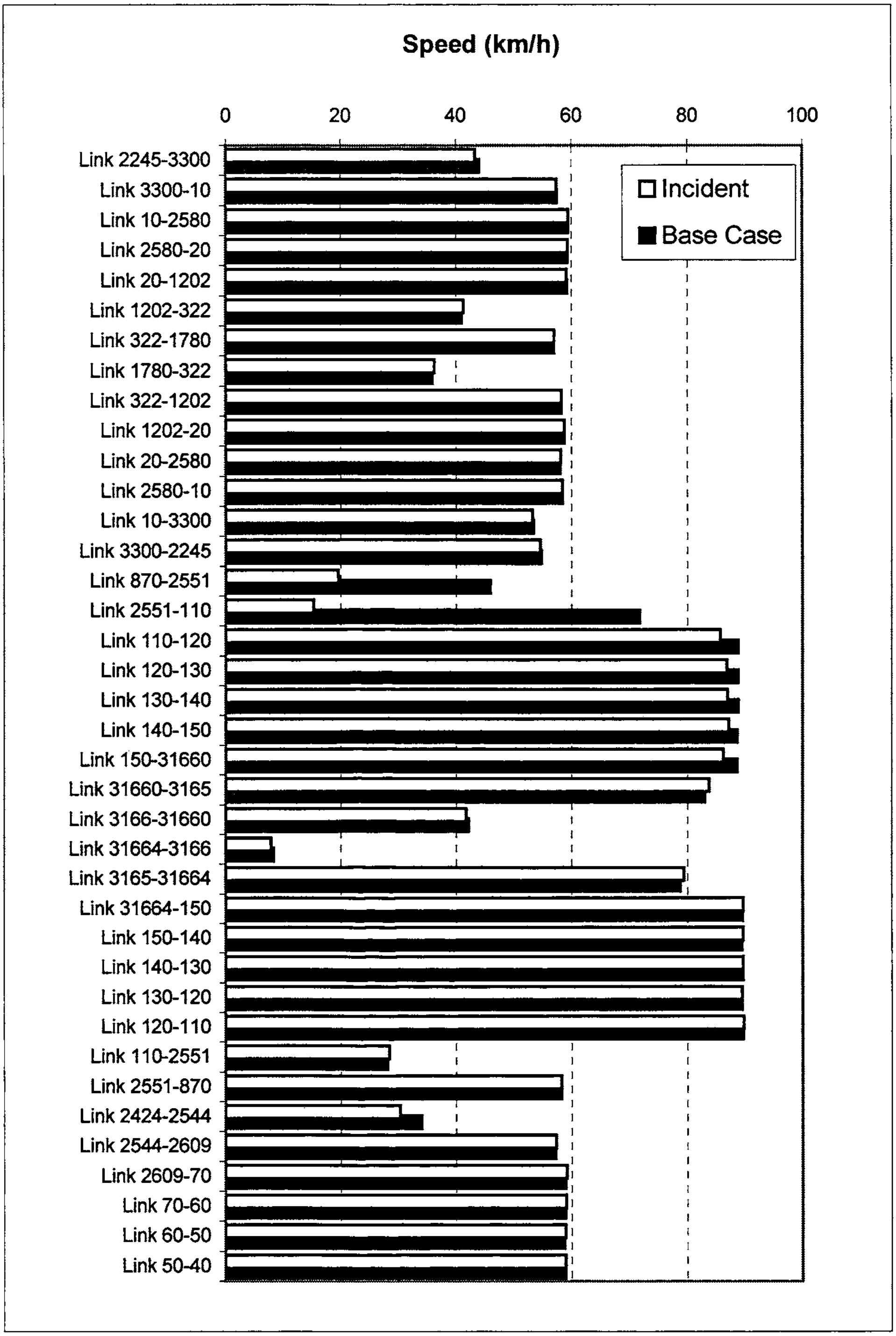


Figure 7.6 Average Link Speed for the Whole Simulation Period (Base & Incident Cases)

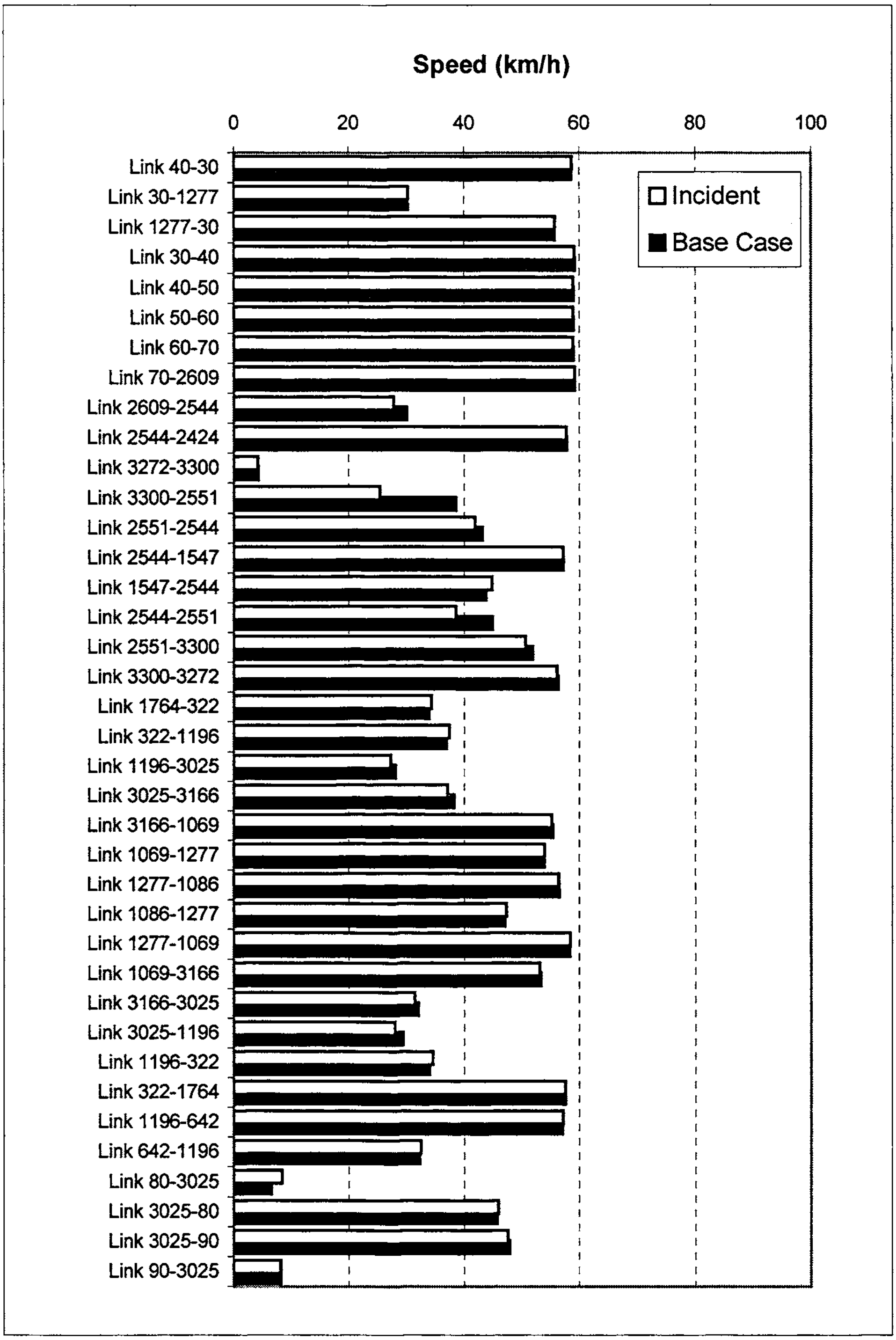


Figure 7.6 (cont.) Average Link Speed for the Whole Simulation Period (Base & Incident Cases)

7.7 Effect of VMS in Managing the M2 Incident (Incident Management Case)

As mentioned in the last section, existence of the specified accident resulted in an increase of 354 veh-hr in the whole network travel time. This number emphasizes the importance of introducing an incident management plan to minimise the accident effect. VMS information was used for that purpose to re-distribute the congested flow over the network and improve the network performance.

The possible locations for displaying VMS information are at links 870-2551, 3272-3300, and 1547-2544, since all of the drivers passing these VMS locations and their normal route includes the accident link and have an alternative route they can divert to. These VMSs will be called VMS-870, VMS-3272, and VMS-1547 in the next sections.

To assess the VMS effectiveness in improving the network performance during the M2 accident, the accident information was displayed through VMS at the three possible locations. This plan will be called "IM1", Incident Management 1, in the next sections. The information displayed at each VMS included: the incident location, "M2", the incident type "Accident", and the expected delay "Delays". The VMS started displaying the accident information 5 minutes after the accident start, 7:05 am, till the end of the accident, 9:00 am, for duration of 115 minutes.

One group of runs, five simulation runs, was made with the specified accident on the M2 motorway and the VMS information. The total network travel time was calculated for 15-minute time intervals as well as for the whole simulation period. The results were compared with both incident and base cases.

Figure 7.7 shows the travel time, in veh-hour, for the whole network for 15-minute time intervals for the base, incident, and incident management 1 cases. Surprisingly, it was found that displaying information at the 3 VMS resulted in an increase in travel time.

It was also found that, the total travel time for the whole network when displaying VMS information in the defined three locations is 3179 veh-hr compared to 2986 veh-hr in the accident case. Accordingly, the used VMS resulted in 193 veh-hr increase in the network travel time.

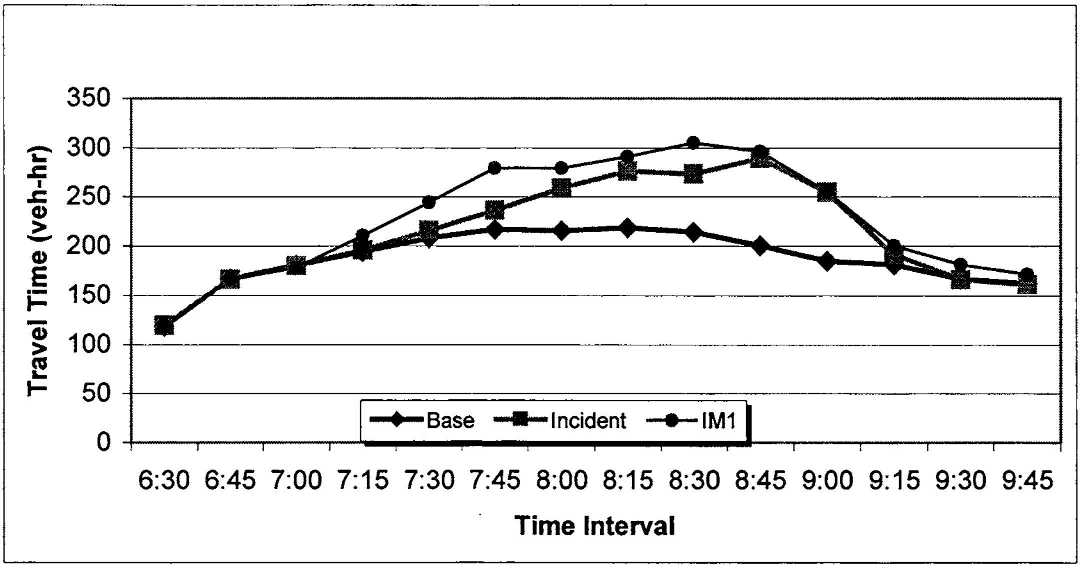


Figure 7.7 Total Network Travel Time for 15-minute Time Intervals (Base, Incident, and IM1 Cases)

To explore the effect of IM1 on the different links, the total link travel time was calculated for the whole simulation time. Figure 7.8 shows the travel time, in veh-hour, for each link for the whole simulation period for the base, incident, and IM1 cases. Displaying the 3 VMS decreased the travel time for links 2551-110, the incident link, and 150-31660 from 88 to 14 veh-hr, and from 100 to 60 veh-hr. Also, travel time for links 870-2551, and 3300-2551 decreased from 383 to 151 veh-hr and from 130 to 71 veh-hr. These links represent part of the M2, and roads leading to the incident link of M2: Abott Road Eastbound and Old Windsor Road Southbound. On the other hand, the travel time of links 2551-3300 and 1202-322 increased from 30 to 180 veh-hr and from 74 to 316 veh-hr. Furthermore, the travel time increased for links 2245-3300 and 3272-3300 from 20 to 146 veh-hr and from 249-271 veh-hr. These links represent parts of the alternative routes: Old Windsor Road Northbound, and Seven Hills Road Eastbound; and roads leading to these alternatives: Seven Hills Road Eastbound, and Old Windsor Road Southbound.

It can be concluded that, the management plan IM1 shifted the problem, the congestion associated with the accident, to some of the alternative routes rather than minimising it. Thus, it was decided to investigate the effect of displaying the VMS information at two locations only to reduce the volume diverted to the alternative routes.

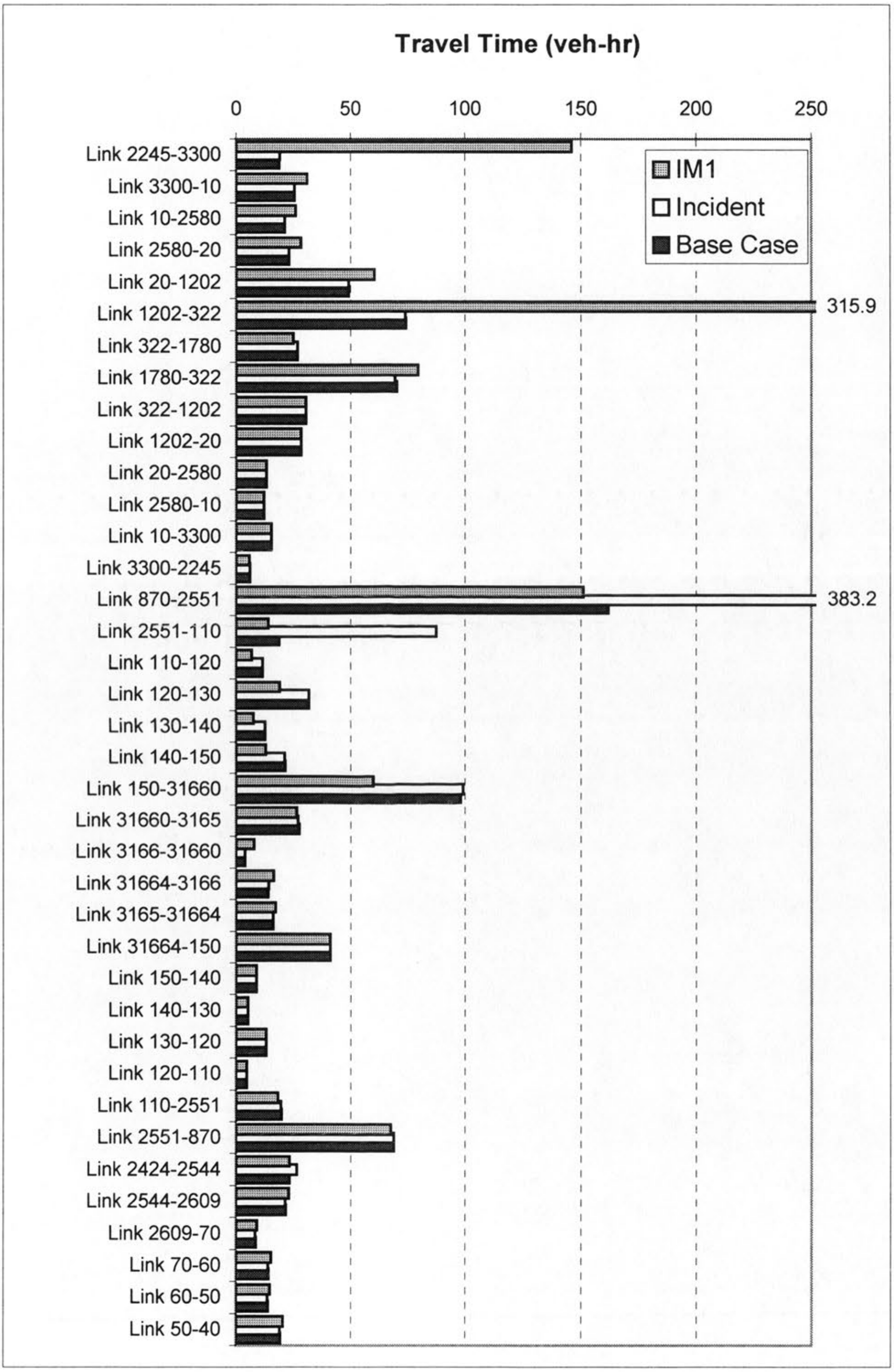


Figure 7.8 Total Link Travel Time for the Whole Simulation Period (Base, Incident, and IM1 Cases)

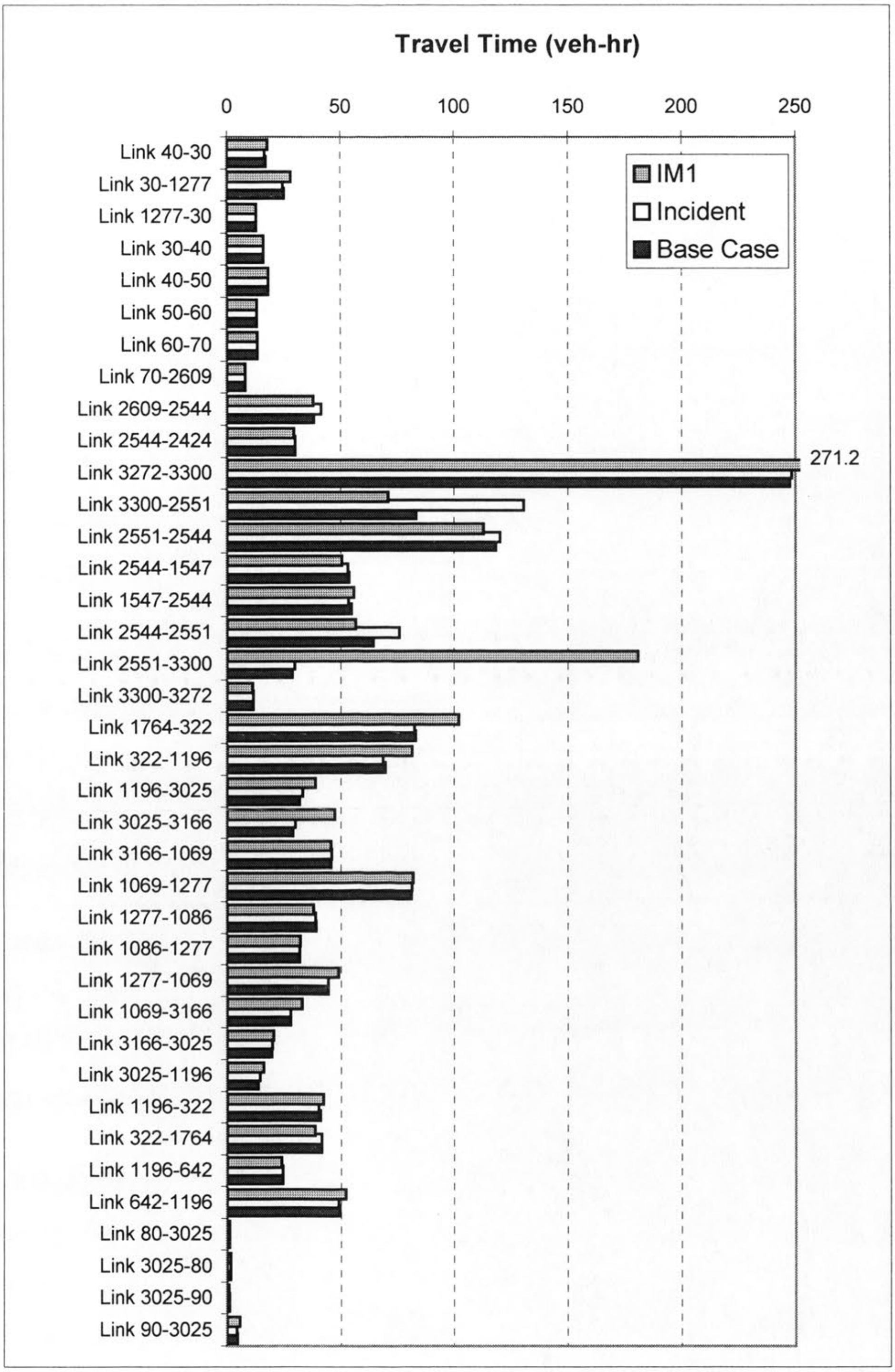


Figure 7.8 (cont.) Total Link Travel Time for the Whole Simulation Period (Base, Incident, and IM1 Cases)

To determine the appropriate two locations for displaying the VMS information, three management plans were considered to include all the possible combinations of the VMS locations. The first plan displayed both VMS-3272, and VMS-1547 and will be called IM2. The second plan displayed VMS-870 and VMS-3272 and will be called IM3. The third plan, which will be called IM4, displayed both VMS-870 and VMS-1547.

Three group of runs, fifteen simulation runs, were made with the specified accident on the M2 motorway. Each group of runs included one incident management plan IM2, IM3, or IM4. The total network travel time was calculated for 15-minute time intervals as well as for the whole simulation period. The results were compared with both incident and base cases.

Figure 7.9 shows the travel time, in veh-hour, for the whole network for 15-minute time intervals for the base, incident, and IM2, IM3, and IM4 cases. IM3 increased the travel time while IM4 does not have an obvious effect on the travel time. On the other hand, the network travel time decreased as a result of the IM2 plan and it become closer to the network travel time in the base case, the case without accident.

It was also found that, IM2 decreased the total travel time for the whole network by 325 veh-hr. On the other hand, IM3 increased the travel time by 198 veh-hr which is very close to IM1. While, the travel time for the IM4 plan is nearly the same as the accident case without displaying any information.

From the above analysis it can be concluded that, the IM2 is an efficient plan for minimising the effect of the specified M2 accident, since it saves network travel time of 325 veh-hr. The IM2 plan will be called IM in the next sections since it was selected as the optimum incident management plan for the studied case.

It is clear that the use of VMS as an incident management tool is very beneficial in improving the overall network performance during incidents. On the other hand, this analysis shows that it is crucial to carry out a careful and detailed analysis for the possible locations of displaying the VMS information for the considered case in order to identify the plan which is able to optimise the network performance.

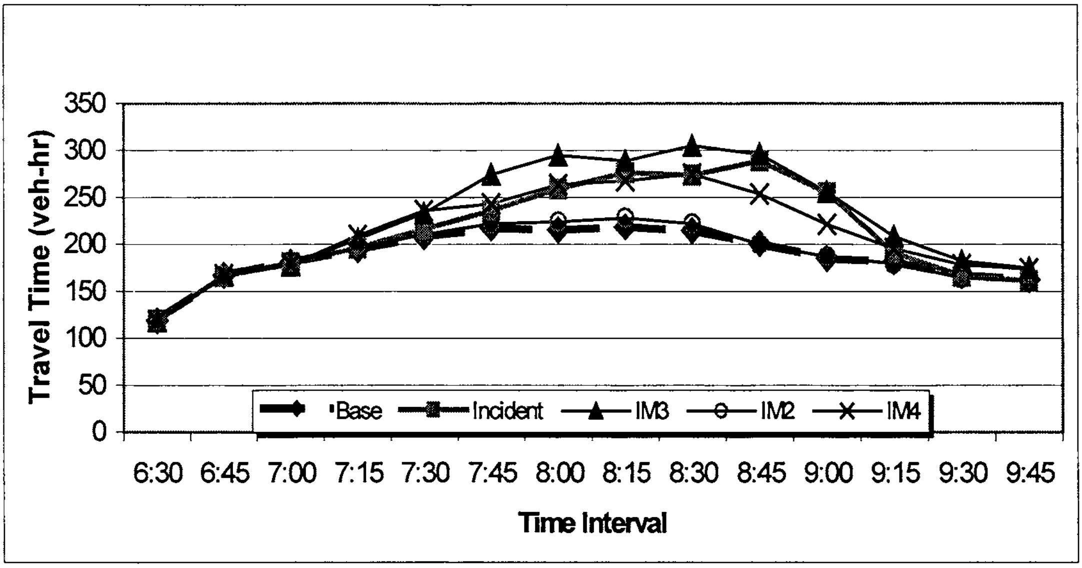


Figure 7.9 Total Network Travel Time for 15-minute Time Intervals (Base, Incident, and IM2, 3, and 4 Cases)

7.7.1 Effect of the Incident Management Plan, IM, on the Network Links

To explore the effect of the IM plan on the different links, the total link travel time was calculated for the whole simulation time. Figure 7.10 shows the travel time, in veh-hour, for each link for the whole simulation period for the base, incident, and incident management, IM cases. The IM plan decreased the travel time on the accident link, 2551-110, from 87 to 47 veh-hr. In addition, the travel time decreased by more than 50% from 383 to 159 veh-hr for link 870-2551 upstream the accident link. Also, for links 3300-2551 and 2544-2551, which are located upstream of the incident link, the travel time increased from 131 to 80 veh-hr and from 76 to 59 veh-hr respectively. Overall, it can be concluded that the incident management plan, IM, decreased the travel time for the links affected by the accident to values close to the base case without accident, except on the accident link, 2551-110. Meanwhile, the IM did not cause any noticeable increase in the travel time of the alternative routes. The maximum benefits was obtained from the IM plan because the two parallel alternatives of the M2, Seven Hills Rd and Caroline Chisholm Dr, are close to their free-flow speeds in the base case as described earlier. At the same time, the IM plan diverted an optimum number of vehicles to these alternatives to maintain their flow at an uncongested level.

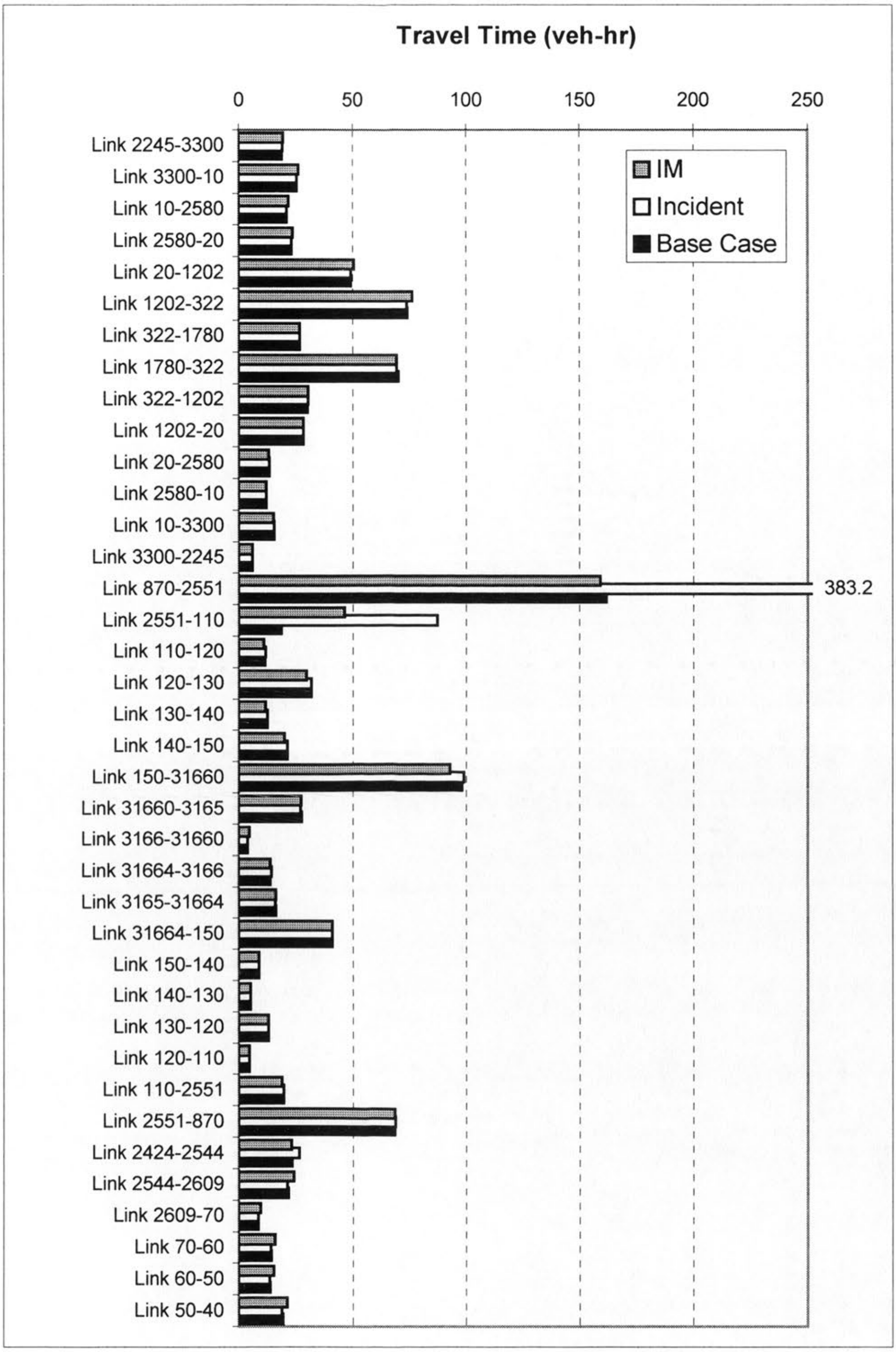


Figure 7.10 Total Link Travel Time for the Whole Simulation Period (Base, Incident, and IM Cases)

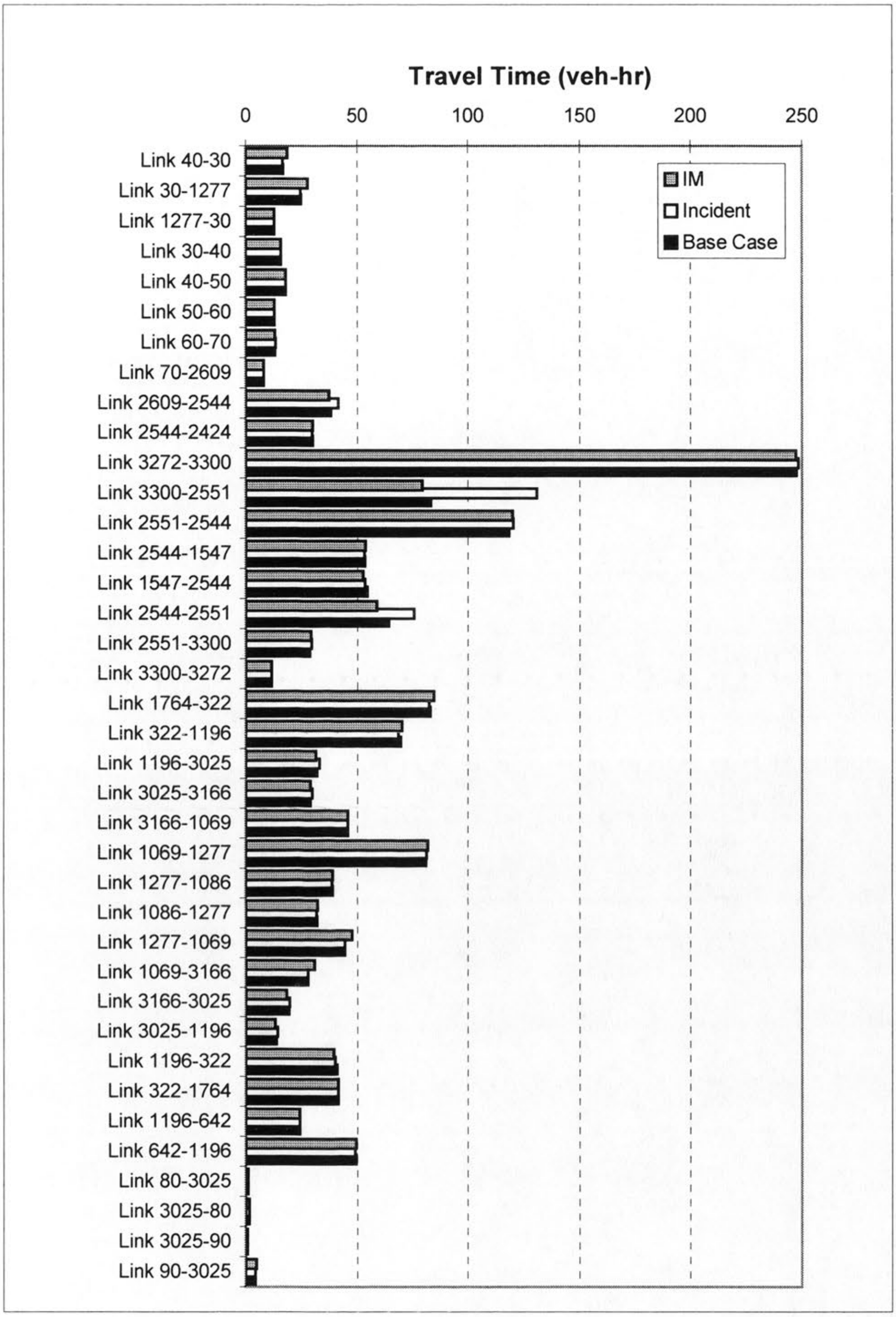


Figure 7.10 (cont.) Total Link Travel Time for the Whole Simulation Period (Base, Incident, and IM Cases)

Figure 7.11 shows the speed, in km/hour, for each link averaged over the whole simulation period for the base, incident, and incident management, IM cases. The IM plan increased the speed of the accident link, 2551-110, 12 km/hr from 15 to 27 km/hr. In addition, speed increased from 20 to 47 km/hr, more than double, for link

870-2551. Also, for links 3300-2551 and 2544-2551, the speed increased from 25 to 40 km/hr and from 39 to 46 km/hr. Overall, it can be concluded that, the IM plan increased the speed of the links affected by the M2 accident to values close to the base case without accident, with the exception of the accident link, 2551-110. Figure 7.12 to Figure 7.15 show the speed variations by 15-minute time interval for the base, incident, and incident management IM cases for these links.

Figure 7.11 Average Link Speed for the Whole Simulation Period (Base, Incident, and IM Cases)

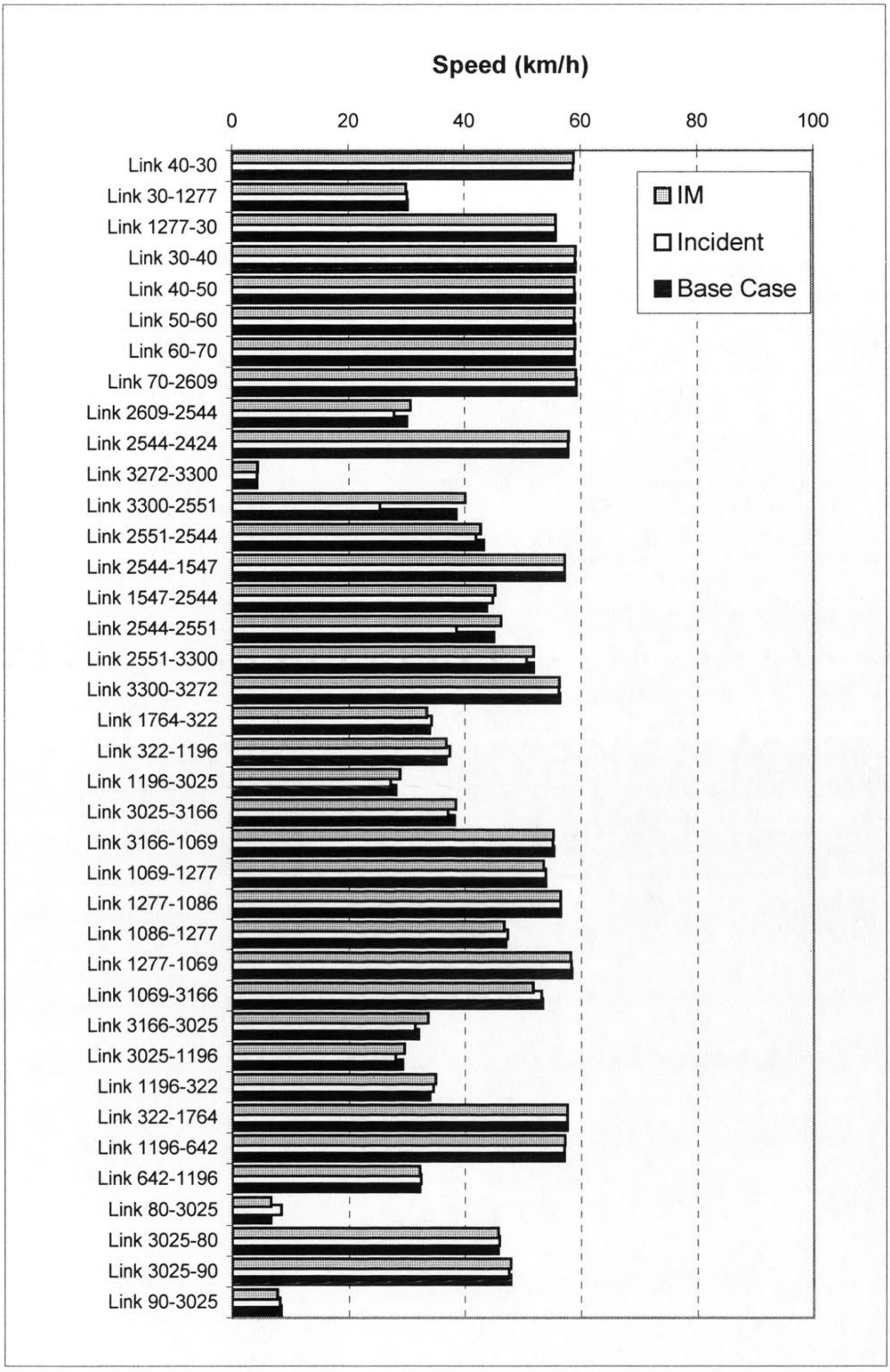


Figure 7.11 (cont.) Average Link Speed for the Whole Simulation Period (Base, Incident, and IM Cases)

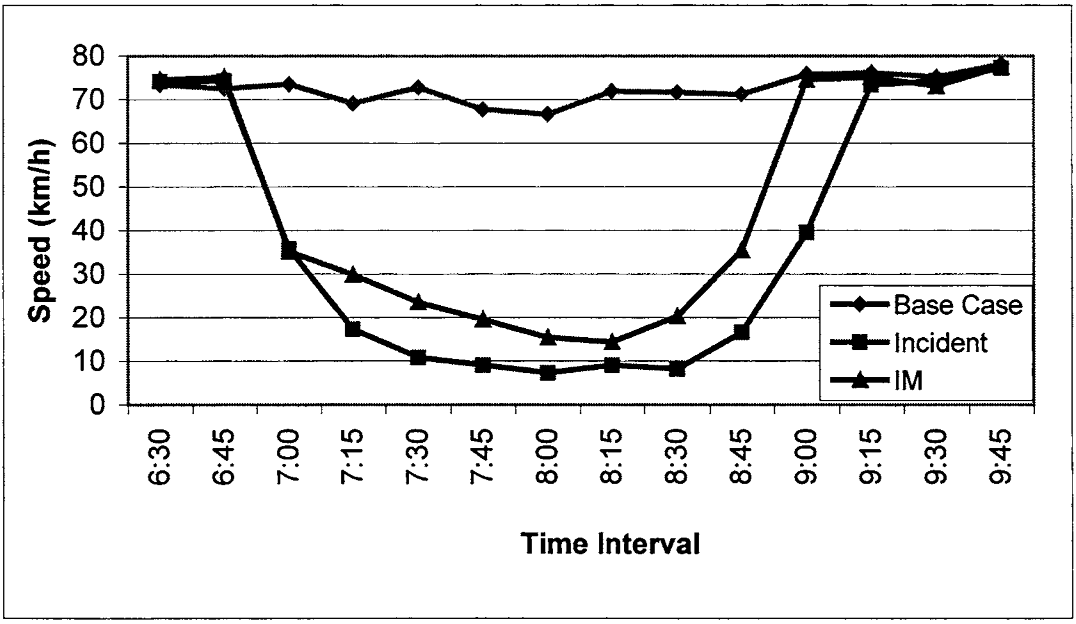


Figure 7.12 Average Speed for Link 2551-110 for 15-minute Time Intervals (Base, Incident, and IM Cases)

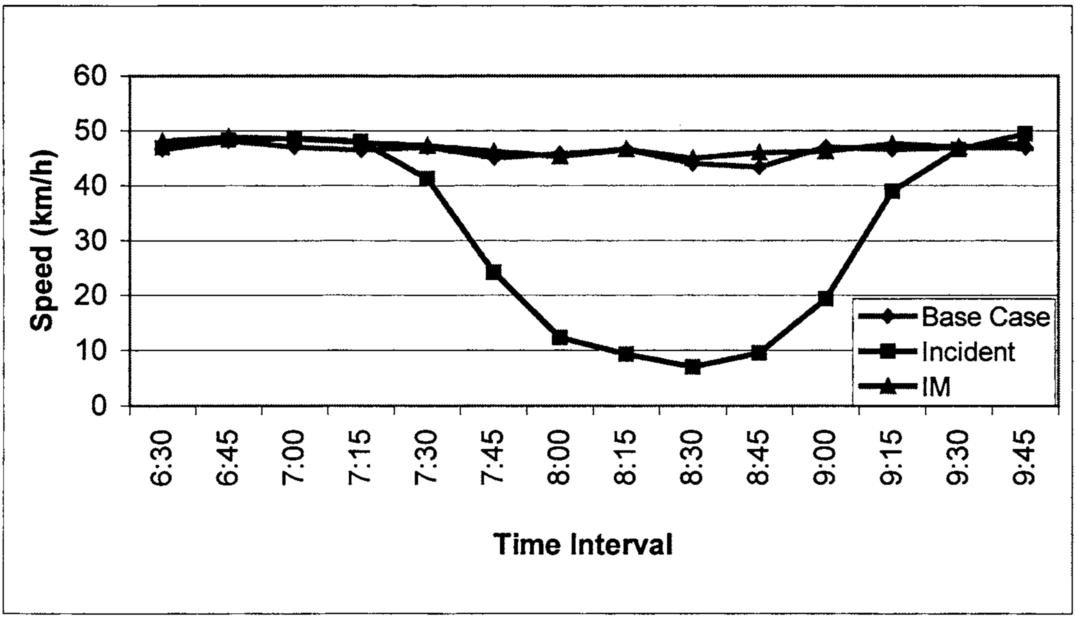


Figure 7.13 Average Speed for Link 870-2551 for 15-minute Time Intervals (Base, Incident, and IM Cases)

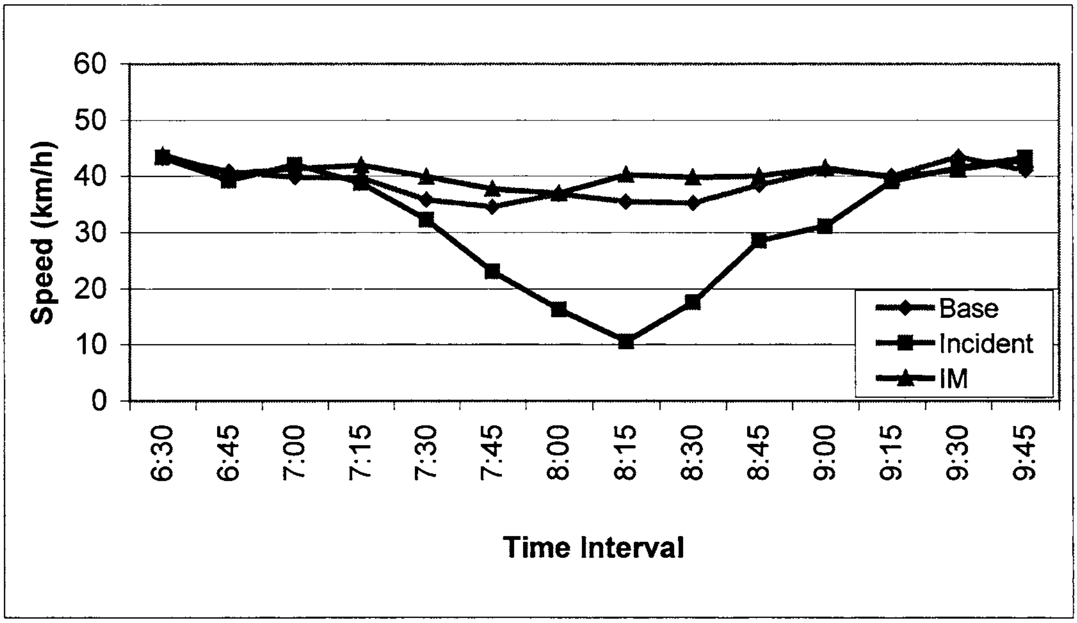


Figure 7.14 Average Speed for Link 3300-2551 for 15-minute Time Intervals (Base, Incident, and IM Cases)

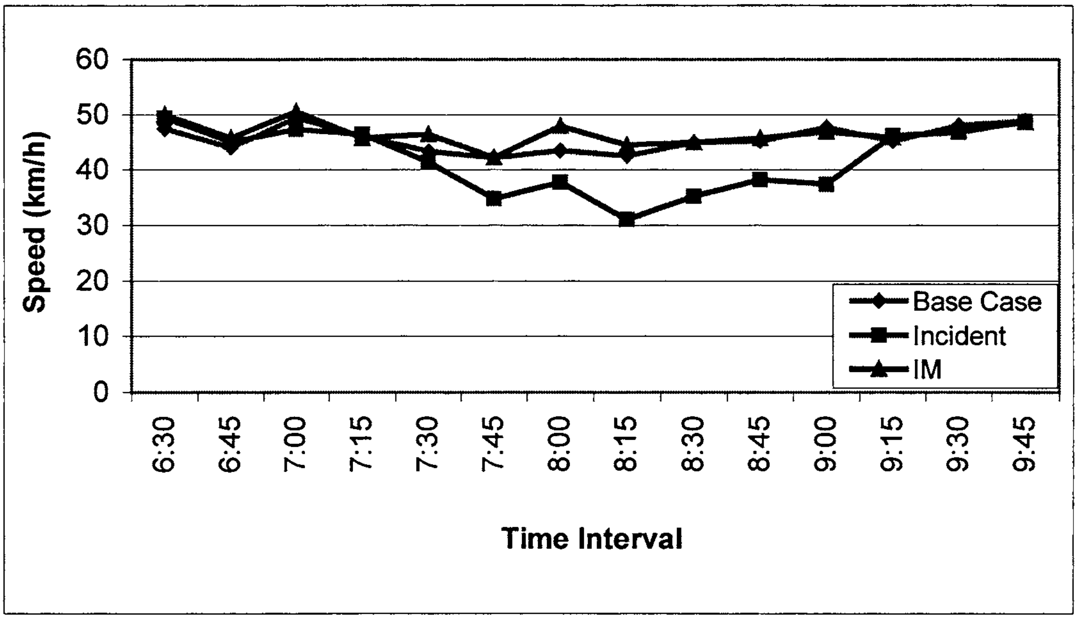


Figure 7.15 Average Speed for Link 2544-2551 for 15-minute Time Intervals (Base, Incident, and IM Cases)

7.8 EFFECT OF FLOW RATES ON THE BENEFITS OF THE INCIDENT MANAGEMENT PLAN IM

The purpose of this analysis is to determine the effect of increasing the flow rate of the accident link on the usefulness of the incident management plan IM. Since the flow rate is defined for the origins rather than for links, the generated flow rate from node 870 was selected to be increased. That is because about half of the flow rate generated from node 870 passes the incident link 2551-110. Four levels of flow rates were introduced by increasing the flow rates generated from node 870 by 5%, 10%, 15% and 20%. For each flow level, three groups of runs, 15 simulation run, were made; one group for each case: base, incident and the IM plan. A total of 12 groups of runs, 60 simulation run, were made for the four flow levels. For each group of runs, the total network travel time was calculated for the whole simulation period. Also, for each flow level the saving in travel time was calculated as the difference in the network travel time between the incident case and the incident management case.

Figure 7.16 shows the effect of flow level on the total network travel time for the base, incident, and IM cases, and Figure 7.17 shows the effect of flow level on the saving in travel time resulting from the IM plan. Increasing the flow rate by 5% decreased the saving in travel time by about 45 veh-hr, 13%. In addition, increasing the flow rate by 10% decreased the saving in travel time by about 175 veh-hr, 55%; while, increasing the flow rate 20% resulted in about 225 veh-hr, 70%, decrease in the travel time saving. Also, the effect on the travel time saving of 15% increase in the flow rate is nearly the same as the increase of 10%. It can be concluded that, increasing the flow rate by 5% has a little effect on the saving of travel time, but increasing the flow rate by 10% has a clear effect which is similar to the increase of 15%. Overall, increasing the flow level resulted in decrease in the saving of travel time resulting from the IM plan.

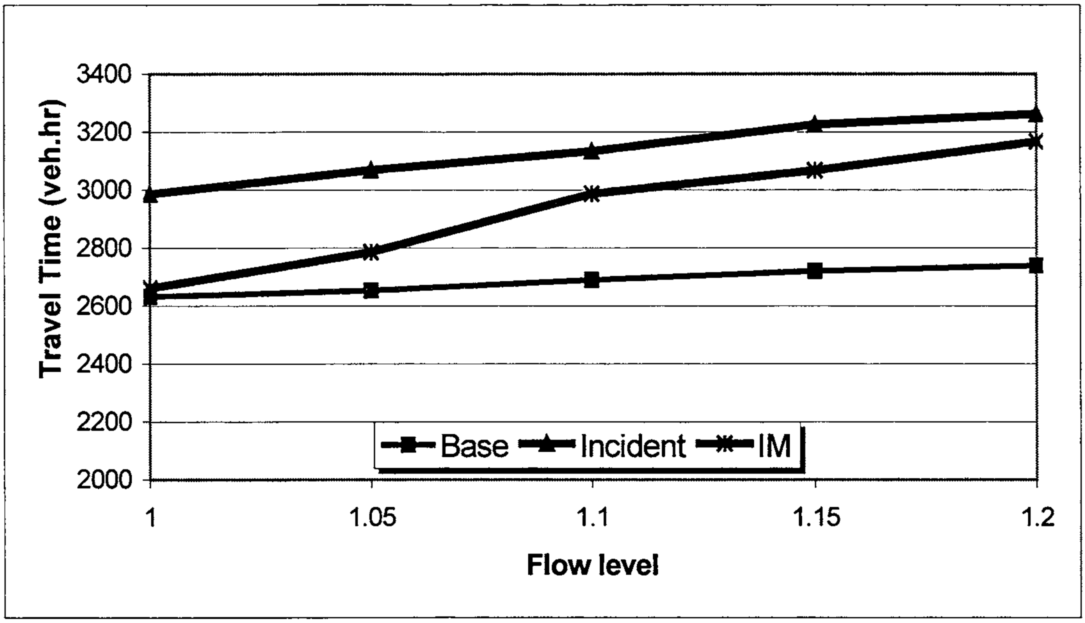


Figure 7.16 Effect of Flow Level on Total Network Travel Time for Base, Incident, and IM Cases

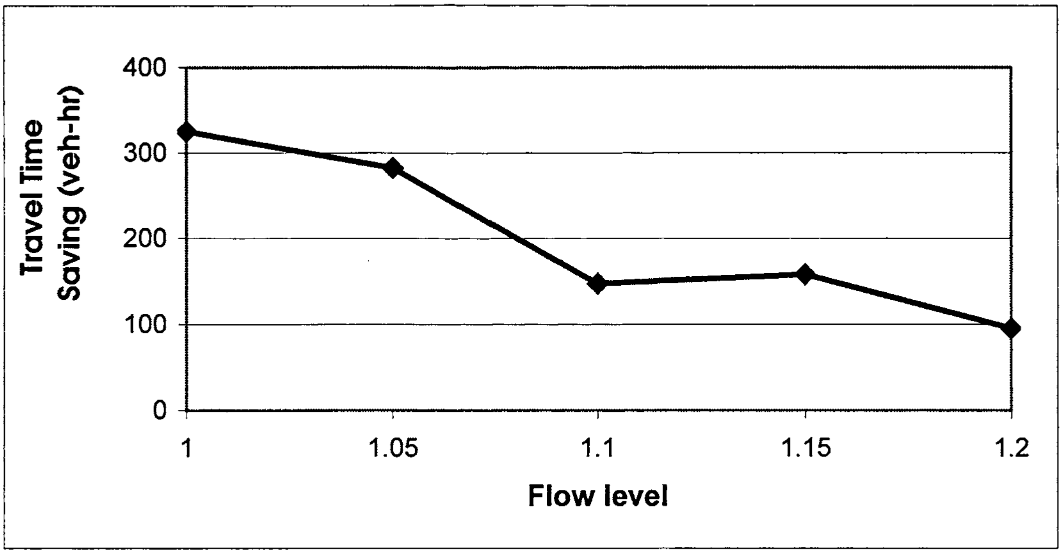


Figure 7.17 Effect of Flow Level on the Total Network Travel Time Saving Resulting from the Incident Management Plan IM

CHAPTER 8
SUMMARY, CONCLUSIONS AND FUTURE RESEARCH

8.1 SUMMARY

A survey was conducted to investigate drivers' route choice behaviour in the presence of different VMS information for any trip in the Sydney Metropolitan Region. The survey utilised the stated preference technique in which each person has to state how he/she would behave in response to different scenarios. The collected data was analysed to reveal the sample characteristics and to explore the effect of the survey parameters on the diversion rate.

A general route choice model was developed which can be used to predict the diversion probability in response to various VMS message contents. The model development included four main steps: model formulation, model building, testing of the model fit, and model validation. The form of the logistic models was chosen for the developed model. Building the model was performed through four stages: (a) selection of the variables and verification of the importance of each independent variable included in the model, (b) checking collinearity among the independent variables and suggesting modifications if needed, (c) checking the linearity in the logit and suggesting modifications if required, and (d) checking if interaction terms need to be included among the independent variables in the model.

A parametric study was performed to analyse the effect of the different explanatory variables on the probability of diversion.

The developed VMS model was incorporated in the SITRAS simulation model to enable the analysis of the effect of using VMS on the overall network performance. The model implemented in Sitras was verified and found to be appropriate for the task.

An assessment of the benefits of using VMS as an incident management tool was performed through the M2 Hills Motorway case study. Different Incident

Management (IM) Plans were introduced and the optimum plan, which gives the maximum benefits of using VMS, was recommended. Also, the effect of increasing the flow rate of the incident link on the effectiveness of VMS, for the recommended incident management plan, was investigated.

8.2 CONCLUSIONS

Based on the work presented in this research, the following conclusions can be drawn:

(a) The probability of diversion increases as the displayed delay time on the usual route increases. Also, the probability of diversion in case of long delay is higher than for delays.

(b) The incident type does not have an obvious effect on the probability of diversion when the displayed severity is long delay and delay in minutes, while it has a clear effect when the displayed severity is delays. The probability of diversion in case of accident is higher than congestion and roadworks when the displayed severity is delays.

(c) The effect of long delay is equivalent to the effect of 20 minutes delay in case of accident and roadworks, and 23 minutes delay in case of congestion. In addition, the effect of delays is equivalent to the effect of 15, 13, and 7 minutes delay in case of accident, congestion, and roadworks.

(d) Drivers are less likely to divert as the difference in travel time between the alternative and the usual route, ETT, increases in normal conditions. Also, the probability of diversion decreases with the increase of trip travel time.

(e) The diversion rate increases with drivers' familiarity with the alternative route.

(f) The probability of diversion decreases with the existence of visible queue at the alternative route, while it increases with the presence of visible queue at the usual route.

The following section to be added after section 8.2

8.3 IMPLICATIONS FOR PRACTICE

The following results are crucial for the design and use of VMS messages as part of traffic management schemes. (points: a, b, and c to be deleted from section 8.2: conclusions)

(a) The incident type does not have an obvious effect on the probability of diversion when the displayed severity is LONG DELAY and delay in minutes, while it has a clear effect when the displayed severity is DELAYS. The probability of diversion in case of ACCIDENT is higher than CONGESTION and ROADWORKS when the displayed severity is DELAYS.

(b) The effect of LONG DELAY is equivalent to the effect of 20 minutes delay in case of ACCIDENT and ROADWORKS, and 23 minutes delay in case of CONGESTION. In addition, the effect of DELAYS is equivalent to the effect of 15, 13, and 7 minutes delay in case of ACCIDENT, CONGESTION, and ROADWORKS.

(c) The probability of diversion increases as the displayed delay time on the usual route increases. Also, the probability of diversion in case of LONG DELAY is higher than for DELAYS.

(g) The willingness to divert at next potential diversion points increases the probability of diversion.

(h) Drivers' attributes, age and sex, do not affect the probability of diversion. Also, the trip purpose, drivers' assessment of previous VMS information, and drivers' familiarity with the usual route do not have a significant effect on the probability of diversion.

(i) The developed VMS model has the ability to predict the probability of diversion resulting from various VMS message contents for any car trip in Sydney Metropolitan Region.

(j) The VMS model was successively implemented and verified in Sitras, which enables to analyse the VMS impacts on network performance and hence the benefits of using the variable message signs as an incident management tool can be evaluated.

(k) The use of VMS in managing a specified accident on M2 Hills Motorway resulted in 325 veh-hr saving in the total travel time of the specified network. And as a result, the total network travel time became closer to the total network travel time without accident.

(l) The use of VMS as an incident management tool can be very beneficial in improving the overall network performance during incidents. But, it is crucial to carry out a careful and detailed analysis of the possible management measures, including various combinations of the location and wording of displayed VMS information, in order to identify the most appropriate incident management plan to optimise the network performance.

(m) Increasing the flow rate on the incident link by 5% has little effect on the saving of travel time, a 13% decrease, but increasing the flow rate by 10% has a clear effect, 55% decrease, which is similar to the effect of increasing the flow rate by 15%. While, increasing the flow rate 20% resulted in about 70% decrease in the travel time saving. Overall, increasing the flow level resulted in decrease in the saving of travel time resulting from using VMS information.

8.3 CONTRIBUTIONS OF THE RESEARCH PROJECT

The research presented in this thesis mainly involves the development of a route choice model in presence of VMS information and implementing this model into SITRAS simulation model to evaluate the benefits of using VMS on the network performance as an incident management tool. Main tasks of research included literature review, survey the effect of VMS on route choice behaviour, development of VMS model, implementation of the VMS model into SITRAS simulation model and case study of M2 Hills Motorway. Overall contributions of the research project are outlined as follows:

- A general model was developed for predicting the effect of VMS information on drivers' route choice behaviour in the Sydney Metropolitan Area. This model can generally be applied anywhere in Sydney at any location regardless of the trip origin, destination and trip length. No models of this kind were available in Australia. Also, this model overcomes limitations imposed by available models overseas. All of the overseas studies were based on one or two fixed trips, therefore the resulting models are specific to the given trip only and are not suited for the application, as general models, anywhere else. Furthermore, the developed model tested and considered the effect of drivers' willingness to divert at next potential diversion points. This variable has not been tested or considered before in any of the overseas models.

- Validation of the developed VMS model was performed using stated preference data collected for different trips in Sydney Metropolitan Area.

- The developed VMS model was implemented in SITRAS simulation model to evaluate the network benefits of using VMS. That enables to analyse the effect of VMS on the overall network as well as the incident link. To our knowledge, no similar process has been implemented in the current simulation models. The current simulation models, which consider the VMS information, are based on applying some assumptions or using a random process for the diversion of drivers passing the VMS rather than incorporating a realistic VMS model; and that does not reflect the real effect of VMS on the network perfromance

- Evaluation of the benefits of using VMS as an incident management tool was performed through the M2 Hills Motorway case study. Different Incident Management (IM) Plans were tested and the optimum plan, which gives the maximum benefits of using VMS, was recommended. Also, the effect of increasing the flow rate of the incident link on the effectiveness of VMS, for the recommended incident management plan, was investigated.

The developed VMS model has been validated and implemented into SITRAS simulation model. Thus, evaluation the effect of displaying VMS information can be performed for anywhere in Sydney under the given traffic conditions. This analysis is considered very useful for developers, traffic planners, and traffic authorities in exploring the impacts of displaying VMS information prior to implementation.

8.4 FUTURE RESEARCH

Despite all of the contributions and benefits that recognised from this research, we found that some aspects are needed for future work as follows:

(a) Collecting information on the effect of physical road characteristics, road surface conditions, road class for both the usual and alternative routes on the drivers' route choice behaviour in response to Variable Message Signs. Also, collecting information on the effect of weather on the drivers' response to VMS.

(b) Analysing the statistical significance of the factors mentioned above and incorporating the significant factors into the VMS model.

(c) Quantifying the benefits of using VMS as an incident management tool in terms of savings in fuel consumption and reducing vehicle emissions. Accordingly, the environmental improvements of using VMS can be evaluated.

(d) A field study is desirable for more validation for the developed VMS model. The VMS model was developed and verified based on data collected from stated preference, SP, survey. This survey type has a lot of advantages and the literature supports its use and reveals that the SP responses are fairly close to the real responses. On the other hand, the main shortcoming of the SP survey is related to the fact that individuals are not committed to behave in real life in accordance with their SP responses.

REFERENCES

Abdel-aty, M. A., Vaughn, K. M., and Kitamura, R. 1994, 'Models of Commuters' Information Use and Route Choice: Initial Results Based on Southern California Commuter Route Choice Survey', *Transportation Research Record* 1453, Transportation Research Board, Washington, D. C., pp 46-55

Abdel-aty, M. A., Kitamura, R., and Jovanis, P. P. 1995, 'Impact of ATIS on Route Choice', *Proceedings of the Transportation Congress-Key to the World Infrastructure Conference*, San Diego, California, pp. 304-314.

Abdel-aty, M. A., Kitamura, R., and Jovanis, P. P. 1997, 'Using Stated Preference Data for Studying the Effect of Advanced Traffic Information on Drivers' Route Choice', *Transpn. Res.*, vol. 5C, no. 1, pp 39-50.

Agresti, A. 1996, *An Introduction to Categorical Data Analysis*, Wiley, New York, USA.

Algers, S., Bernauer, E., Boero, M., Breheret, L., Di Taranto, C., Dougherty, M., Fox, K., and Gabard, J. 1997, 'A Review of Micro-Simulation Models', *SMARTEST Project Deliverable D3.*

Barcelo, J., Casas, J., Ferrer, J. L., and Garcia, D., 'Modelling Advanced Transport Telematic Applications with Microscopic Simulators: the Case of AIMSUN2', *Contribution to the 25th Anniversary of CRT/8/13/98*, <http://www.tss-bcn.com/crtpap1st.pdf>, 1998 (20 March 2001).

Ben-Akiva, M., and Lerman, S. R. 2000, *Discrete Choice Analysis: Theory and Application to Travel Demand*, 8th edn, MIT Press, Cambridge, UK.

Benson, B. G. 1996, 'Motorist Attitudes About Content of Variable-Message Signs', *Transportation Research Record* 1550, Transportation Research Board, Washington, D. C., pp 48-57

Bonsall, P., and Parry, T. 1991, 'Using an Interactive Route-Choice Simulator to Investigate Drivers' Compliance with Route Guidance Advice'. *Transportation Research Record 1306*, Transportation Research Board, Washington, D.C., pp. 59-68.

Bonsall, P. 1994a, 'Simulator Experiments and Modelling to Determine the Influence of Route Guidance on Drivers' Route Choice', *Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, Paris, pp. 964-972.

Bonsall, P. 1994b, 'Driver Response to VMS- QUO VADIS Investigations', *Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, Paris, pp. 1221-1228.

Bonsall, P. W., and Merrall, A. C. 1995, 'Analysing and Modelling the Influence of Roadside Variable Message Displays on Drivers' Route Choice', *Proceedings of the 7th World Transport Research Conference*, Sydney, Australia, pp. 11-25.

Bonsall, P., Firmin, P., Anderson, M., Palmer, I., and Balmforth, P. 1997, 'Validating the Results of a Route Choice Simulator', *Transpn. Res.*, vol. 5C,no. 6, pp. 371-387.

Bonsall, P., and Palmer, I. 1998, 'Route Choice in Response to Variable Message Signs- Factors Affecting Compliance', *Proceedings of the 8th World Transport Research Conference*, Antwerp, Belgium.

Bovy, P. H. L. and Stern, E. 1990, *Route Choice: Wayfinding in Transport Networks*, Kluwer Academic Publisher, Dordecht, Netherlands.

Brocken, M. G., and Van der Vlist, M. J. 1991, 'Traffic Control with Variable Message Signs', *Proceedings of Vehicle Navigation and Information Systems Conference*, pp. 27-45

Burrell, J. E. 1968, 'Multipath Route Assignment and Its Application to Capacity Restraint', *Proceedings of the Fourth International Symposium on the Theory of Traffic Flow*, Karlsruhe, Germany, pp. 210-219.

Chatterjee, K., and Hounsell, N. 1998, 'Modelling Driver Response to Variable Message Signs With RGCONTRAM', *Proceedings of the 8th World Transport Research Conference*, Antwerp, Belgium.

Chatterjee, K., Hounsell, N. B., Waterson, B. J., Firmin, P. E., and Bonsall, P. W. 2000, 'Evaluation of the London Driver Information System: Results from the CLEOPATRA Study', *Proceedings of the 10th International Road Transport Information and Control Conference*, London, U.K., pp. 22-26.

Commeignes, H., 1992, *The Cost of Congestion in Sydney*, a report prepared for the Roads and Traffic Authority of NSW, Pricing Strategy Branch.

Conquest, L., Spyridakis, J., Haselkorn, M., and Barfield, W. 1993, 'The Effect of Motorist Information on Commuters Behavior: Classification of Drivers into Commuter Groups', *Transpn. Res.*, vol. 1C, no. 2, pp 183-201.

Cramer, J. S. 1991, *The Logit Model: an Introduction for Economists,* Edward Arnold, London U.K.

Demaris, A. 1992, *Logit Modelling: Practical Applications*, Sage University Paper series on Quantitative applications in the Social Science, no. 07-086, Newbury Park, CA.

Demaris, A. 1995, 'A Tutorial in Logistic Regression', *Journal of Marriage and the Family*, vol. 57, no. 4, pp 956-968.

Dia, H., Harney, D., and Boyle, A. 2000, 'Analysis of Commuters' Responses to Travel Information: Implications for ATIS Deployment in Brisbane', *Proceedings of the 22nd Australian Institute of Transport Research Conference (CAITR 00)*, Canberra, Australia.

Emmerink, R. H. M., Nijkamp, P., Rietveld, P., and Ommeren, J. N. 1996, 'Variable Message Signs and Radio Traffic Information: An Integrated Empirical Analysis of Drivers' Route Choice Behavior', *Transpn. Res.*, vol. 30A, no. 2, pp 135-153.

Greene, W. H. 1998, *LIMDEP Version 7:00 User Manual,* Econometric Software Inc., Plainview, NY, USA

Grenzeback, L. R., and Woodle C. E. 1992, 'The True Costs of Highway Congestion', *ITE Journal*, pp. 16-20.

Hall, M. D., Van Vliet, and Willumsen, L. G. 1980, 'SATURN -A Simulation-Assignment Model for the Evaluation of Traffic Management Schemes', *Traffic Engineering and Control*, vol. 21, no. 4, April, pp. 168-176.

Hato, E., and Taniguchi, M. 1994, 'A study on Efficiency of the Driver Information System in the Tokyo Metropolitan Area ', *Proceedings of Vehicle Navigation and Information Systems Conference*, Yokohama, Japan, pp. 401-404.

Hensher, D. A., and Button, K. J. (ed.) 2000, *Handbook of Transport Modelling*, Handbooks in Transport, Pergamon, U.K.

Hidas, P., and Behbahanizadeh, K. 1995, 'Urban Transport Network Simulation: an Object-Oriented Approach', *Proceedings of the 4th International Conference on Computers in Urban Planning and Urban Management*, Melbourne, Australia, pp. 229-243.

Hidas, P., and Behbahanizadeh, K. 1998, 'SITRAS: A Simulation Model for ITS applications', *Proceedings of the 5th World Congress on Intelligent Transport Systems,* Seoul, Korea.

Hidas, P., and Behbahanizadeh, K. 1999, ' Microscopic Simulation of Lane Changing Under Incident Conditions', *Proceedings 14th International Symposium on Transportation and Traffic Theory (ISTTT)*, Haifa, Israel, pp. 53-70.

Hidas, P. 2001, 'Simulation Modelling For Incident Management', *Proceedings of the 24th Australasian Transport Research Forum*, Hobart, Australia.

Hounsell, N. B., Chatterjee, K., Bonsall, P. W., and Firmin, P. E. 1998, ' Variable Message Signs in London: Evaluation in Cleopatra', *Proceedings of the 9th*

International Road Transport Information and Control Conference, London, U.K., pp. 217-221.

Hosmer, D. W., and Lemeshow, S. 1989, *Applied Logistic Regression,* Wiley, New York, USA.

James, M. L., and Davies, M. W. 1986, 'SATURN Traffic Management Model Evaluation', *11th Australian Transport Research Forum*, Darwin, pp. 182-198

Judycki, D. C., and Robinson J. R. 1992, 'Managing Traffic during Nonrecurring Congestion', *ITE Journal*, pp. 21-26.

Khattak, A. J., Schofer, J. L. and Koppelman, F. S. 1991, 'Factors Influencing Commuters' Enroute Diversion Behavior in Response to Delay', *Transportation Research Record* 1318, Transportation Research Board, Washington, D. C., pp 125-136

Khattak, A. J., Schofer, J. L. and Koppelman, F. S. 1993a, 'Commuters' Enroute Diversion and Return Decision: Analysis and Implications for Advanced Traveler Information Sysytems', *Transpn. Res.*, vol. 27A, no. 2, pp 101-111.

Khattak, A. J., Koppelman, F. S., and Schofer, J. L. 1993b, 'Stated Preference for Investigating Commuters' Diversion Propensity', *Transportation,* vol. 20, pp 107-127.

Khattak, A. J., Schofer, J. L. and Koppelman, F. S. 1994, 'Effect of Traffic Information on Commuters' Propensity to Change Route and Departure Time', *Journal of advanced Transportation*, vol. 29, no. 2, pp 193-212.

Koing, R., Saffran, A., and Langbein, R. 1994, 'Modelling of Drivers'-Reaction to Traveller Information Services', *Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, Paris, pp. 1774-1781.

Koing, R., Saffran, A., and Breckle, H. 1994, 'Modelling of Drivers'-Behavior', *Proceedings of Vehicle Navigation and Information Systems Conference*, Yokohama, Japan, pp. 371- 376.

Koo, R., and, Yim, Y. 1998, 'Commuter Response to Traffic Information on an Incident', *Transportation Research Record* 1621, Transportation Research Board, Washington, D. C., pp 36-42

Leonard, D., and Gower, P. 1982, 'User Guide to CONTRAM Version 4', *Transport and Road Research Laboratory*, Supplementary Report 735.

Leonard, D., Gower, P., and Taylor, N. 1989, 'CONTRAM: Structure of the Model', *Transport and Road Research Laboratory*, Research Report 178.

Liao, T. F. 1994, *Interpreting Probability Models: Logit, Probit and other Generalized Linear Models*, Sage University Paper series on Quantitative applications in the Social Science, no. 07- 101, Thousand Oaks, CA.

Mc Donald, M., Hounsell, N. B., and Njoze, S. R. 1995, 'Strategies for Route Guidance Systems Taking Account of Driver Response', *Proceedings of Vehicle Navigation and Information Systems Conference*, Seattle, pp. 328-333.

Mc Donald, M. and Lyons, G. D. 1996, 'Driver Information', *Traffic Engineering and Control*, vol. 37, no. 1, January, pp. 10-15.

Mc Donald, M., and Richards, A. 1996, 'Urban Incident Management Using Integrated Control and Information Systems', *Proceedings of the 8th International Road Traffic Monitoring and Control Conference*, London, U.K., pp. 188-191.

Mc Donald, M., Richards, A., Morris, R., and Sharpe, J. 1998, ' The Development of VMS Strategies', *Proceedings of the 9th International Road Transport Information and Control Conference*, London, U.K., pp. 212-216.

Menard, S. W. 1995, *Applied Logistic Regression Analysis*, Sage University Paper series on Quantitative applications in the Social Science, no. 07- 106, Thousand Oaks, CA.

MVA Consultancy 1987, The Value of Travel Time Savings, *Policy Journals*, Newbury, Berkshire.

Organization for Economic Co-Operation and Development (OECD) 1987, Dynamic Traffic management in Urban and Suburban Road Systems, OECD, Paris.

Pampel, F. C. 2000, *Logistic Regression: a Primer*, Sage University Paper series on Quantitative applications in the Social Science, no. 07- 132, Thousand Oaks, CA.

'Paramics Traffic Simulation', *Quadstone Limited, 16 Chester Street, Edinburgh, UK.*. <http://paramics.quadstone.com>, 1998, (28 July 1999)

Rathi, A. K., and Santiago, A. J. 1990, 'Urban Network Traffic Simulation: TRAF-NETSIM Program', *Journal of Transportation Engineering,* vol. 116, no. 6, pp. 734-742.

Rathi, A. K., and Venigalla, M. M. 1993, 'Variance Reduction Applied to Urban Network Traffic Simulation'. *Transportation Research Record 1365*, Transportation Research Board, Washington, D.C., pp. 133-146.

Richardson, A. J., Ampt, E. S., and Meuburg, A. H. 1995, *Survey Methods for Transport Planning*, EUCALYPTUS Press, Australia.

Roper, D. H. 1990, ' Freeway Incident Management', *NCHRP Synthesis of Highway Practice*, Transportation Research Board, Washington, D. C.

Spyridakis, J., Barfield, W., Conquest, L., Haselkorn, M.,and Isakson, C. 1991, 'Surveying Commuters Behavior: Designing Motorist Information Systems', *Transpn. Res.*, vol. 25A, no. 1, pp 17-30.

Taylor, N. B. 1990, 'CONTRAM 5: An Enhanced Traffic Assignment Model', *Transport and Road Research Laboratory*, Research Report 249.

Thomas, R. 1991, *Traffic Assignment Techniques*, Avebury Technical, Aldershot, England

Uchida, T., Iida, Y., and Nakahara, M. 1994a, 'Empirical Analysis on Travel Information and Route Choice Behaviour', *Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems*, Paris, pp. 1812-1819.

Uchida, T., Iida, Y., and Nakahara, M. 1994b, 'Panel Survey on Drivers' Route Choice Behavior Under Travel Time Information', *Proceedings of Vehicle Navigation and Information Systems Conference*, Yokohama, Japan, pp. 383-388.

Underwood, G., Underwood, J. D. M., Sommerville, F. and Hengeveld, W. 1994, *Information Technology on the Move: Technical and behavioural Evaluations of Mobile Telecommunications*, John Willey & Sons, Chichester, England.

Wardman, M., Bonsall, P. W., and Shires, J. D. 1997, 'Driver Response to Variable Message Signs: A Stated Preference Investigation', *Transpn. Res.*, vol. 5C,no. 6, pp. 389-405.

Van Vliet, D. 1982, 'SATURN-A Modern Assignment Model', *Traffic Engineering and Control*, vol. 23, no. 12, pp. 578-581.

Yang, Q., and Koutsopoulos, H. 1996, 'A Microscopic Traffic Simulator for Evaluation of Dynamic Traffic Management Systems', *Transportation Res.*, vol. 4C, no. 3, pp. 113-129.

APPENDIX A

QUESTIONNAIRE

1. What is the trip purpose?
   Commuting[1] Shopping[2] Entertainment[3] Others[4] (specify):

2. Trip origin: Street: Suburb:

3. Trip destination: Street: Suburb:

4. Describe the usual route you use for your trip:

5. Do you use sometimes any other route? Yes[1] No[2] , ***If Yes***
   Describe this route:

   How do you decide which one to use?

If No:

Is there any other route that you could use? Yes No , ***If Yes***
Describe this route:

For the remaining part of the questionnaire, the questions will focus on the section of the usual route which has an alternative, rather than the whole route, and the diverted section.

6. What is the estimated typical travel time of each route under normal conditions
   usual route section :
   alternative section :

7. While you are on the way to your destination, imagine that before you approach the intersection, at which you could divert to the other route, you see VMS saying:
   Which route would you select? Usual[1] Alternative[2]

   If The usual route
   If you see visible queue on the usual route in addition to that sign.
   Which route would you select? Usual Alternative

   If The alternative route
   If you see visible queue on the alternative route in addition to that sign.
   Which route would you select? Usual Alternative

8. The previous question with VMS saying:
   The selected route: Usual Alternative
   Vis-Q : Usual Alternative

9. The previous question with VMS saying:
   The selected route: Usual Alternative
   Vis-Q : Usual Alternative

10. The previous question with VMS saying:
   The selected route: Usual Alternative
   Vis-Q : Usual Alternative

11. Are there any later points at which you could alter your route?
   Yes No , ***If Yes***
   When you come to the next diversion point, would you divert if you are faced with excessive delays? Yes No

12. How much experience did you have before with VMS? Alot[1] Little[2] Nil[3]
   If not Nil
   How did you find the information from VMS?
   Very satisfactory[1] satisfactory[2] uncertain[3] Very unsatisfactory[4]

13. How often do you travel on the usual route?
   Every day[1] few times a week[2] once a week[3] less[4]

14. How often do you travel on other routes between your origin and destination?
   Few times a week[1] few times a month[2] once a month[3] less[4]

15. Age: 17-35[1] 35-50[2] > 50[3] year

16. Sex: Male Female

The following questions to be answered by the interviewer :

1. What was the respondent's degree of interest in the survey?
   Very Interested interested not interested careless
2. Did the respondent give any additional information or opinions relevant to the survey? Yes No ***If Yes***
   What did he/she say?
3. Did you observe any important notes on the interview which you need to mention? Yes No ***If Yes***
   Describe:

4. Did you check your questionnaire? Yes No , ***If No***

   Please review the questionnaire

Sketch of the usual and the alternative routes

Interviewer Name: Date: Sheet No.

APPENDIX B
INTERVIEWER MANUAL

B.1 INTERVIEWER INSTRUCTIONS

1- Introductory paragraph to be said to the respondent at the beginning of each interview:

Interviewer: *We are doing a survey on how the drivers will select their routes in the presence of displayed information by Variable Message Signs. This survey is done as a part of a research study at the UNSW.*

2- Each Interviewer should try to select their respondents such as:

- **45%** of the total respondents: < **35** years old
- **40%** of the total respondents: **35-50** years old
- **15%** of the total respondents: ≥ **50** years old

Also, the interviewers should try to select their respondents such as:

- **75%** + of the total respondents are **commuter drivers** (drivers who regularly drive to and from work/school)

Also, the interviewers should try to select their respondents such as:

- **40% of the total respondents are females**
- **60% of the total respondents are males**

3- When asking question 1, the interviewer should clarify to the respondent that we interested in the trip he/she usually use his/her car for. If the respondent is used to use his car for more than one trip purpose, the interviewer should select the appropriate trip for the survey according to the following priorities:

a- The Commuting trips, if it is included in the respondent trip purposes,

Otherwise

b- The Longer trip

4- In question 1, if the respondent doesn't understand the meaning of commuting, the interviewer should explain that this means the regularly driving to and from work.

5- Trip origin/destination is the place at which the trip starts/ends, (e.g., for commuting, trip origin is the home address and trip destination is the work/school address).

6- The usual route & the alternative route (at Q4& 5) should be described by the street names. Also, its required to draw a sketch for them (as in the map) in the allocated space at the end of the questionnaire using different line types such as the continuous line for the usual route and the dash line for the alternative route.

7- In question No. 5: *How do you decide which one to use?* If the respondent can't answer or understand how to answer, the interviewer can address the following categories to the respondent (**only for explanation rather than enforce him for any answer**):

avoid traffic lights[1]	*avoid congestion*[2]
avoid heavy vehicles[3]	*avoid Pedestrian crossing*[4]
avoid Toll[5]	*safer*[6]

8- If the respondent has not used any other route before (Q5), the interviewer should try to have the respondent select a potential alternative route by asking:

Is there any other route that you ***could*** *use*?

If the respondent can't come up with an alternative route that he/she thinks as a possibility then, the interview should not be completed.

9- If the respondent has more than one intersection point at which he can divert to another route, The interviewer should deal with the intersection point which leads to the longest usual route and diverted sections.

10- The questionnaire should not be completed if the travel time **from the diversion point** is less than 10-15 minutes (question 6).

11- The required VMS content to be used for each interview should depend on the travel time of the usual route section. The following table shows the possible VMS signs that can be displayed to the respondent according to the travel time.

Travel time (Minutes)	Possible VMS Signs		
10-15	A1 to A3,	R1 to R3,	C1 to C3
15-20	A1 to A4,	R1 to R4,	C1 to C4
20-30	A1 to A5,	R1 to R4,	C1 to C4
> 30	All the signs		

The interviewer should select the VMS signs from the above table **such as:** at least one accident sign (A), one roadworks sign (R), and one congestion sign (C) should be displayed at each interview. These guides are valid until you are given other instructions during the survey.

Note that, you have to use the signs with equal rate, e.g., if you used A1 four times you have to try using each sign from A2 to A6 four times, and the same for C1 to C6 and R1 to R6.

12- After each interview, the interviewer should:

- make a valuable assessment of the validity of the recorded answers by noting the interest of the respondent in the survey (Very Interested, interested, not interested, careless)
- write any additional information or opinions given by the respondent such as: It is better to put a question about …….. , VMS should advice the drivers with the travel time instead of the delay and/or with the available alternatives.
- record any notes observed on the interview
- do field editing to ensure that all questions were asked and all answers were recorded. If the questionnaire is not complete, then the interviewer can edit the missing information which were given by the respondent and not recorded. Also, the interviewer can return immediately to the respondent to obtain the missing information, which were not asked by the interviewer or given by the respondent.

13- The interviewers should return the first 2/3 completed questionnaires to the supervisor before more work will be done. This is to ensure that, the interviewers' errors can be detected before conducting more interviews.

14- Each interviewer has to send a report each week to the supervisor including:

a- the number of the completed interviews which have been conducted

b- the number of the recorded answers associated with each VMS sign in a table form as follows:

VMS	A1	A2	A3	A4	A5	A6
No. of answers						
VMS	R1	R2	R3	R4	R5	R6
No. of answers						
VMS	C1	C2	C3	C4	C5	C6
No. of answers						

This report can be sent by e-mail to the following address: emad@civeng.unsw.edu.au

15- Each interview should have Sydney map during each interview

16- Each interview has to return the completed questionnaire forms to the supervisor at the end of the survey period in addition to a Microsoft Excel file contains the entered data.

B.2 Data Entry and Coding Instructions

Each interviewer has to carry out the coding process and data entry in addition to conducting the interviews.

B.2.1 Data Coding

It is recommended to write the answers codes inside the allocated boxes at the questionnaire form. The questionnaire answers should be coded as follows:

- The questions which have "Yes/No" answers should be coded as "1" for yes and "2" for no

- the questions which have "Usual/Alternative route" answers should be coded as "1" for the usual route and "2" for the Alternative route
- The "Male/Female" answers should be coded as "1" for male and "2" for female
- The answers representing the quantities of physical attributes such as travel times should be coded as the numbers which representing actual data (time in minutes)
- In the questions that contain menu items, the answer should be coded using the assigned number to it at the questionnaire form.
- The VMS signs should be coded as the sign name, e.g., A1, A2......
- The missing data should be coded as " "
- A number will be assigned to each interviewer at the training session.

B.2.2 Data Entry

Data entry should be carried out using the Microsoft Excel, which provides many facilities for data entry. Data should be entered such as the rows will represent data items for each questionnaire, while the columns will represent different respondents to the questionnaire. The designed data entry screen will be distributed to the interviewers.

APPENDIX C

VMS MESSAGES USED IN THE SURVEY

Usual Route

Accident Ahead

Long Delays

A1

Usual Route

Road works Ahead

Long Delays

R1

Usual Route

Congestion Ahead

Long Delays

C1

Usual Route

Accident Ahead

Delays

A2

Usual Route

Road works Ahead

Delays

R2

Usual Route

Congestion Ahead

Delays

C2

Usual Route

Accident Ahead

10 Minutes Delay

A3

Usual Route

Road works Ahead

10 Minutes Delay

R3

Usual Route

Congestion Ahead

10 Minutes Delay

C3

Usual Route

Accident Ahead

15 Minutes Delay

A4

Usual Route

Road works Ahead

15 Minutes Delay

R4

Usual Route

Congestion Ahead

15 Minutes Delay

C4

Usual Route

Accident Ahead

20 Minutes Delay

A5

Usual Route

Road works Ahead

20 Minutes Delay

R5

Usual Route

Congestion Ahead

20 Minutes Delay

C5

Usual Route

Accident Ahead

30 Minutes Delay

A6

Usual Route

Road works Ahead

30 Minutes Delay

R6

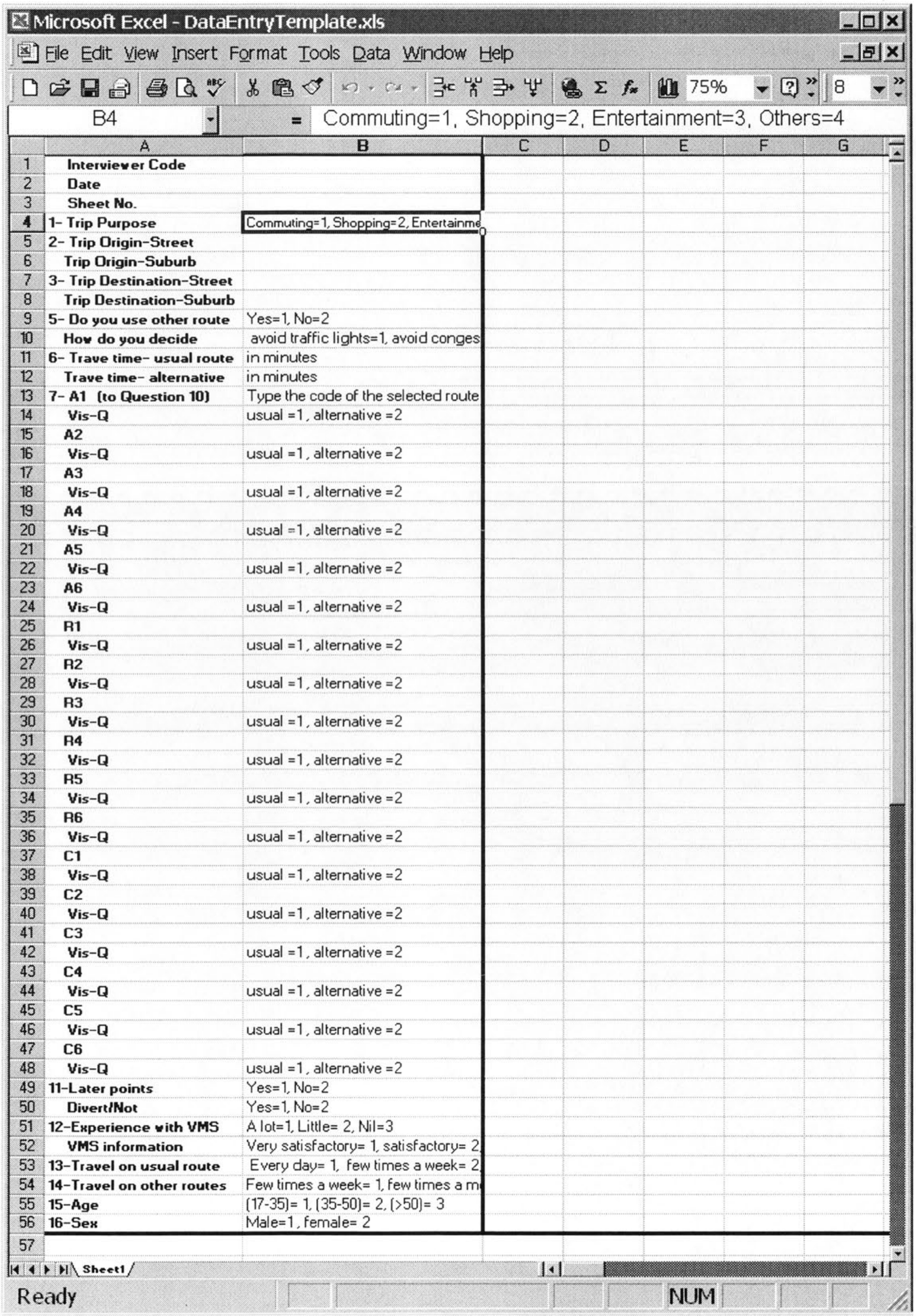
Usual Route

Congestion Ahead

30 Minutes Delay

C6

APPENDIX D
DATA ENTRY SCREEN



Microsoft Excel - DataEntryTemplate.xls

B4 = Commuting=1, Shopping=2, Entertainment=3, Others=4

	A	B
1	Interviewer Code	
2	Date	
3	Sheet No.	
4	1- Trip Purpose	Commuting=1, Shopping=2, Entertainme
5	2- Trip Origin-Street	
6	Trip Origin-Suburb	
7	3- Trip Destination-Street	
8	Trip Destination-Suburb	
9	5- Do you use other route	Yes=1, No=2
10	How do you decide	avoid traffic lights=1, avoid conges
11	6- Trave time- usual route	in minutes
12	Trave time- alternative	in minutes
13	7- A1 (to Question 10)	Type the code of the selected route
14	Vis-Q	usual =1, alternative =2
15	A2	
16	Vis-Q	usual =1, alternative =2
17	A3	
18	Vis-Q	usual =1, alternative =2
19	A4	
20	Vis-Q	usual =1, alternative =2
21	A5	
22	Vis-Q	usual =1, alternative =2
23	A6	
24	Vis-Q	usual =1, alternative =2
25	R1	
26	Vis-Q	usual =1, alternative =2
27	R2	
28	Vis-Q	usual =1, alternative =2
29	R3	
30	Vis-Q	usual =1, alternative =2
31	R4	
32	Vis-Q	usual =1, alternative =2
33	R5	
34	Vis-Q	usual =1, alternative =2
35	R6	
36	Vis-Q	usual =1, alternative =2
37	C1	
38	Vis-Q	usual =1, alternative =2
39	C2	
40	Vis-Q	usual =1, alternative =2
41	C3	
42	Vis-Q	usual =1, alternative =2
43	C4	
44	Vis-Q	usual =1, alternative =2
45	C5	
46	Vis-Q	usual =1, alternative =2
47	C6	
48	Vis-Q	usual =1, alternative =2
49	11-Later points	Yes=1, No=2
50	Divert/Not	Yes=1, No=2
51	12-Experience with VMS	A lot=1, Little= 2, Nil=3
52	VMS information	Very satisfactory= 1, satisfactory= 2
53	13-Travel on usual route	Every day= 1, few times a week= 2
54	14-Travel on other routes	Few times a week= 1, few times a m
55	15-Age	(17-35)= 1, (35-50)= 2, (>50)= 3
56	16-Sex	Male=1, female= 2
57		

Sheet1

Ready NUM

The first Column, A, contains the questions, which their coded answers should be entered in the file. The second column, B, contains the coding system. The Data from each questionnaire was entered in one column starting from column C.