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Driver Behaviors on Different Presentation Styles of Traffic Information

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This thesis is dedicated to my parents and sisters for their love, endless support and encouragement.

Abstract

Road traffic information has been one of the important elements for traffic information systems. The information can be found on the road where Variable Message Sign (VMS) and other platforms have been widely utilized for such application. These overwhelming majorities of traffic information sources provide real-time traffic information, aiming at helping drivers make better decisions on choosing a correct traffic route on the basis of current traffic state. However, it is an unusual sight to view the full scenarios of the system with the view from the drivers themselves. Therefore, smartly presenting the information to the road user has a potential to support the road user to receive and interpret the information in a more effective way. Traffic information presented in different styles may enhance the attractiveness of the information itself. Considering this, we design this study to find out whether there is a refined relationship between the specific presentation style and the driving behavior.

As a starting point, this study tested the assumption that the probe vehicle could provide reliable and sufficient amount of data that could represent travel time information which then can be transformed into various presentation style. VISSIM 5.0 is used to generate travel time data on a hypothetical network. Average travel time on links are analyzed for various percentages of probe vehicles and compared to the ‘true’ average travel time using ‘bootstrapping’ technique. ArcGIS designed for use by transportation professionals to display the results of travel time provided by probe in a more understandable visual fashion (color coded design).

Later, user testing upon preference of the drivers towards different types of traffic information presentation style is conducted. A picture is often cited to be worth a thousands words and, for some tasks it is clear that a visual presentation such as map is dramatically easier to be used than other textual or spoken description. Visual displays become even more attractive to provide orientation or context, to enable selection of regions and to provide dynamic feedback for identifying change such as dynamic traffic congestion map. In what concerns the visual information, systems can present information using graphics, symbols or even written messages. A stated preference user test is conducted and questionnaires with different types of traffic information presentation style are distributed to the respondents. An underlying question is basically about whether and how the presentation styles of traffic information affect the driver in making their decision. The study addresses a wide range of alternative styles of in-vehicle traffic information as well as stationary information in different driving scenarios (stop and go and congested). The analysis is carried out which contains various trip variables, including route selection characteristics, travel purpose and actual observable traffic conditions en route such as level of congestion, variables pertaining to the information to which is being displayed and also psychological factors based on personal attributes and the experience of the individual drivers. It is assumed that drivers are influenced by these variables and factors of making decisions whether to acquire and refer to traffic information in choosing their route.

Our results revealed that in case of in-vehicle information, presentation style of traffic information does not play a significant role for driver’s behavior. As to the preference of presentation style, ‘map with detail building’ came out to be the highest rank. The main reason for this preference is the presence of the buildings which provides additional orientation information. Different behavior patterns could be observed when confronted with more realistic situations. Our observations demonstrate that the drivers are more likely to divert their route only in rush trip.

In case of stationary information, again, we found no evidence that presentation style of traffic information does play a significant role for driver’s behavior. As to the preference of presentation style, ‘combination of graphic and text information’ came out to be the highest rank. Our observations demonstrate that the drivers are more likely to divert their route only in rush trip and congested route.

Zusammenfassung

Straßenverkehrsinformationen sind eine der wichtigsten Elemente in Verkehrsinformationssystemen. Diese Informationen lassen sich auf der Straße in Echtzeit erfassen, z.B. durch das Wechselverkehrszeichen (Variable Message Sign -VMS). Eine Vielzahl von Verkehrsinformationsquellen liefern aktuelle Verkehrsinformationen, welche den Autofahrern helfen, bessere Entscheidung bei der Auswahl des richtigen Verkehrsweges anhand der aktuellen Verkehrslage zu treffen. Allerdings wäre es dem Fahrer nicht von Vorteil, alle aktuellen Verkehrsinformationen aus der Fahrerperspektive zu erhalten. Daher ist eine elegante Bereitstellung der Informationen maßgebend, um diese effektiver zu empfangen und zu interpretieren. Unterschiedlich dargestellte Verkehrsinformationen können deren Attraktivität vielfach steigern. Unter Berücksichtigung dieses Aspektes führen wir diese Arbeit durch, um herauszufinden, ob es eine relevante Beziehung zwischen spezifischer Präsentationsweise und dem Fahrverhalten gibt.

Zu Beginn dieser Studie wird die Annahme getestet, ob ein verwendetes Versuchs-Fahrzeug eine zuverlässige und ausreichende Menge an Daten liefert, wie z.B. das Vermitteln von Informationen über die Reisezeit durch verschiedene Darstellungsarten. Für diese Studie wurde VISSIM 5.0 benutzt, um die Reisezeit auf einem hypothetischen Netz zu erzeugen. Die durchschnittlichen Fahrzeiten der Verbindungen sind für einige der zu untersuchenden Autos analysiert und danach mit den ‚echten' durchschnittlichen Reisezeiten mittels 'Bootstrapping'-Technik verglichen worden. Außerdem kommt die GIS-Plattform ArcGIS zum Einsatz, um Experten im Bereich Transport die Ergebnisse der echten Reisezeiten in einer visuell verständlichen Darstellung wie z.B. durch Farbcodierung zu vermitteln.

Darüber hinaus wird ein Nutzer-Test zu den Präferenzen der Fahrer gegenüber verschiedenen Darstellungsarten von Verkehrsinformationen untersucht. In dieser Studie wird deutlich, dass eine bildhafte Darstellung, wie z.B. eine Karte, eine einfachere Methode zur Übertragung und zur Nutzung bietet als eine Beschreibung durch einen angezeigten Text oder durch gesprochene Rückmeldung. Visuelle Anzeigen bieten attraktivere Möglichkeiten, um dem Fahrer die Auswahl der gewünschten Region zu ermöglichen oder Änderungen in dynamischen Staukarten zu identifizieren. Besonders bei visuellen Informationen können Systeme vorliegende Informationen mit Grafiken, Symbolen oder auch Texten darstellen. Es wird ein Test mit Fragebögen zu verschiedenen Darstellungsarten der Verkehrsinformationen durchgeführt, um die Präferenzen der Fahrer zu bestimmen. Die grundlegende Frage dabei ist, wie die Darstellungsarten die Entscheidung des Fahrers beeinflußen. Die Studie deckt ein breites Spektrum an alternativen Designs von On-board-Verkehrsinformationen sowie stationären Informationen in verschiedenen Fahrszenarien (Stop-and-Go) ab. Die Analyse wurde in Abhängigkeit von verschiedenen Reise-Variablen durchgeführt. Diese sind die Charakteristiken der Routenwahl, der Reisezweck und die unterwegs tatsächlich beobachtbaren Verkehrsverhältnisse wie z.B. der Grad der Verkehrauslastung. Damit können Variablen in Bezug auf die Informationen, die angezeigt werden und auch psychologische Faktoren, basierend auf persönliche Eigenschaften sowie die Erfahrung der einzelnen Fahrer untersucht werden. Es wird davon ausgegangen, dass die Fahrer bei der Wahl ihrer Route in ihren Entscheidungen von diesen Variablen und Faktoren beeinflusst werden.

In unserer Studie ist es deutlich zu sehen, dass die Präsentationsarten im Falle einer Bordinformation keine wichtige Rolle für das Fahrer-Verhalten spielen. Wenn es um die Präferenz des Präsentationsstils geht, ist die Karte mit Gebäude-Detailinformation zu bevorzugen. Der Hauptgrund für diese Bevorzugung ist die Präsenz der Gebäude, welche zusätzliche Informationen zur Orientierung bieten. Unterschiedliche Verhaltensweisen wurden beobachtet, wenn die Fahrer mit einer realistischen Situation konfrontiert werden.

Dabei ist die Bereitschaft der Fahrer ihre Route zu ändern, nur in Situation in denen sie es sehr eilig hatten, zu erkennen.

Im Falle einer stationären Information fanden wir immer noch keinen Beweis dafür, dass der Präsentationsstil von Verkehrsinformation eine bedeutende Rolle für das Fahrer-Verhalten hat. Bei stationärer Information ergab sich die Kombination von Grafik- und Textinformation als die beliebteste. Aus unseren Beobachtungen ist wiederum zu sehen, dass die Fahrer nur bei langen Staus und Reisen in denen sie es sehr eilig hatten, ihre Route ändern werden.

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Chapter 1

Introduction

1.1 Background

In many cities, traffic congestion is a common problem causing many negative consequences including increases in travel time, reduction in amenity for nearby residents, increased pollution and a general reduction in efficiency of the road network. All this leads to economic loss and the deterioration of core functions within a city. Traffic congestion can be handled in many ways. One of the solutions is by emphasizing more efficient traffic network management, such as the optimizing of traffic signals. Other cities, such as London and Singapore have manipulated the traffic demand side via the use of electronic road pricing and special congestion area charges. Another common approach is to influence driver behavior with various types of communication. This can be done using pre-trip information where the driver decide which route to take beforehand (or even not making the trip by car at all) and on-trip information using signs by side of the road or in-vehicle devices. The main objective is to relieve congestion by diverting drivers onto alternative routes to where the congestion exists.

Klein (2001) came up with a suggestion that traffic information applications directly influence driver behavior (Figure 1.1). As discussed in Goldsberry (2005), this influence can be divided into two categories which are traffic management influence and information influence. For traffic management influence, the actions of traffic managers, for example, information on traffic signals and ramp meters, directly influence road conditions and driver behavior. The second category of influence deals with the impacts of traffic information dissemination on driver behavior. For example, a driver might change his/her route to avoid a gridlock situation at a specific geographic location when he knows about the information.

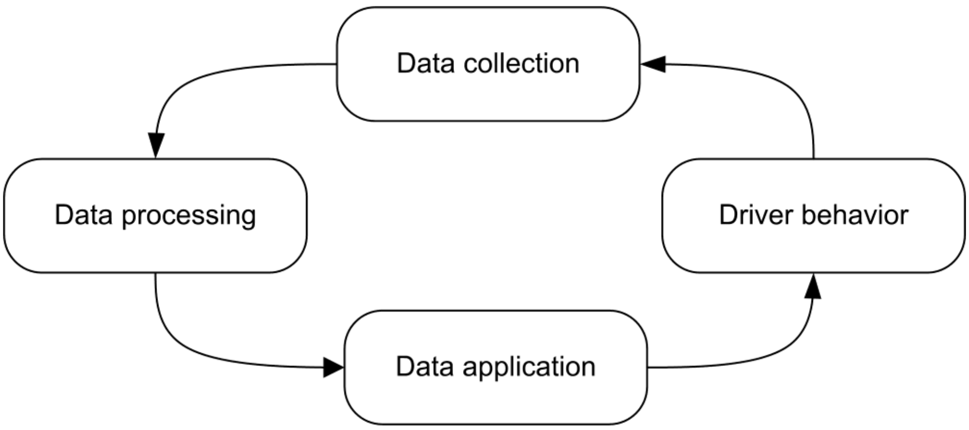


Figure 1. 1 Klein (2001) feedback loop describing the collection, handling, and disseminating of traffic data in real time traffic system as summarized by Goldsberry (2005)

Before traffic information can be received by the driver, there are a few steps that need to be completed before the data can be converted into useful information. These steps include data collection, data processing and data application. In view of the fact that there are a lot of arguments for sufficient and accurate traffic information, many technologies can be used to gather the traffic data. Two basic approaches are suitable for the collection of real-time travel information. One approach relies on sensors at isolated but multiple locations such as inductance loops, infrared cameras and video recorders. These vehicle detectors are capable of collecting information about vehicle volumes, mean speeds, headways, classifications, and lane occupancy. With the implementation of Intelligent Transport System (ITS), another approach is used to collect real-time information. It relies on moving observation platforms that travel in the traffic stream and record information about their progress (Taylor et al. 2000) The moving platforms are instrumented probe vehicles. They maintain frequent communications with a central computer that “tracks” the vehicle location and speed along the traveled route. Point-to-point travel time is the most common and useful information that probe vehicles collects.

The earlier research indicates that the probe vehicle measurement method is a potential method for obtaining traffic information, since it could expand the coverage area of the data and provide reliable data. In addition to the fact that no road-based infrastructure is needed, this method will indirectly reduce the maintenance cost and traffic disturbance. Furthermore, travel time studies based on probe vehicles are widely used to document congestion since the moving vehicle can also act as “portable detectors” that are considered as a valuable source of real-time traffic data. Previous studies have shown the credibility of probe vehicles as source of traffic data. In general, many researchers focus on the accuracy and the effectiveness of the probe system. The present knowledge of using probe vehicles as a source of traffic information can be extended. Pursula (1999) called for the integration of dynamic traffic information and static base map data. Since many municipalities have to continuously collect, process and disseminate traffic information to drivers, they need an efficient platform to conduct these tasks. One of the usages of probe vehicle data is to show the traffic level of service (measurement of effectiveness of elements of transportation infrastructure). However, existing representations are not very effective. Individual drivers are not familiar with the published indexes about the traffic level of service while the visual representations are not easy to understand either.

In this study, the steps to convert the traffic data into useful information and the behavior of the driver once they received the information were combined. Travel time is one of the important elements of a traffic information system. Therefore, it is crucial to make sure this information successfully received and utilized by the driver. Traffic information has the potential to convince drivers to take alternative routes or even change transportation mode from private vehicle to public transport. Our hypothesis is that effective dissemination techniques for traffic information can persuade a driver to change their behaviour in a desired way. Therefore, this study has been designed to answer the following questions:

1. Can the probe vehicle provide a reliable and sufficient amount of data containing travel time information?
2. Will presentation styles of traffic information influence driver’s behavior?
3. How will the driver react on different presentation styles of traffic information while they are in different driving scenarios, from less to the most congested road?
4. Which presentation style will be the most efficient for the individual driving scenarios?

1.2 Scope of the Research

This study is aimed at investigating driver response to different presentation styles of traffic information while they are in different driving scenarios, from less to the most congested road. It is beneficial to conduct a test to investigate whether the driver fully understands the meaning of every detail of the provided traffic information. The presentation technique described in this study provides an idea of a typical style available to gain an insight of probe vehicle data sets. The technique allows users to obtain a visual overview of travel time variation. The presentation style scheme shows an overview of an alternative solution which totally relies on probe vehicles as the data source.

There is also a part of this study to test the assumption that the probe vehicle could provide reliable and sufficient amounts of data that could represent travel time information which then can be presented in different styles. The acquisition of traffic data is bound with enormous effort and it is difficult to capture the reliable data from the real world. In the simulated traffic environments, however, the number of traffic conditions can be varied and controlled, and traffic data can be acquired. Moreover, it is appropriate to conduct the experiment in controlled environments so that the exogenous factors can be eliminated. The research poses a hypothesis that the quality of the data is directly related to the amount of data, or the number of probe vehicles. Therefore, the study also aims at exploring the quality of traffic information from a varying number of probe vehicles.

1.3 Thesis Organization

The dissertation comprises 6 chapters. The first chapter introduces the rationale behind this research; it documents present knowledge and consequent research questions. In addition, it concludes with an overview of the content of the dissertation. Following the general introduction to this study in this chapter, the second chapter describes the fundamental methodology upon the acquisition of traffic data. Many studies have proved that probe vehicles (equipped for the data collection of time-stamped location and speed) are an efficient and inexpensive way to acquire traffic information. Therefore, this chapter introduces fundamental concepts and problems in using probe vehicles. The applications of probe vehicle technology are presented and characteristics of the probe vehicles are also discussed. Subsequently, the third chapter reviews the literature related to the presentation of traffic information. Information presentation is the study of the representation of data, defined as information which has been abstracted in some schematic form. This chapter introduces fundamental concepts and problems approached in presenting useful traffic information to the road user. The applications of visual presentation of information are also presented.

Further on, a review of technical fundamentals for traffic data collection and presentation are reported in chapter four. The research plan combines probe vehicles which act as sources of the traffic information and visual presentation techniques which require user participation. We reconcile the multidisciplinary fields to a single process. The first part of this chapter deals with the process of generating the dataset and the second part addresses the reporting procedure of the information as well as user survey to evaluate driver behavior. Chapter five describes the implementation of traffic data collection and presentation. Two different parts of the analysis are conducted. For the first part, various traffic scenarios were simulated in VISSIM 5.0 simulation model. The simulation yielded several data, including vehicle identification numbers, travel times, origins and destinations, and other traffic data for validation. The results from the simulation were stored in files and then transferred to worksheet for further analysis. Several statistical analyses for the corresponding data were carried out. The key examination was dedicated to the quality of the travel time received from probe vehicles under various traffic and probe (market penetration) conditions. The second part attempted to identify the suitable way of presenting the traffic information. Visual representation using color coded scheme is used and case studies of in-vehicle and stationary information were carried out. Later, the results of driver preferences towards traffic information presentation style and the effects towards driver behavior are presented. Finally, chapter six concludes this study and provides an outlook for future work.

Chapter 2

The probe vehicles for travel time acquisition

2.1. Traffic time and its acquisition methods

Traffic information is important for both traffic management systems, such as Intelligent Transport Systems and road users. Accurate travel time information can help reduce the congestion and its associated costs, and ameliorate the environmental impacts. Moreover, it can also assist the commercial fleets to promote their service quality by delivery in particular time windows. The increasing trust on travel time information indicates a need to accurately and reliably measure travel times. In recent times, real time traffic information services have received a particular focus because the implementation of Intelligent Transportation Systems (ITS) has resulted in the development of systems capable of monitoring roadway conditions and disseminating traffic information to travelers in a network. However, the limited data collection systems do not yet allow the acquisition of sufficient information. This impedes not only the operators from exercising better traffic management but also drivers from making proper driving decisions. The traffic engineer faces a challenge of how to derive from limited data sources sufficient and accurate information which is qualitatively as good as the information from multiple data sources. Another challenge tackles the question of whether we should expand observation coverage or improve the accuracy of roadways that are already covered. Normally, when accuracy is high, it is a good decision to expand coverage. Conversely, when observation coverage is already extensive, improving accuracy over the existing coverage may be a better option.

Travel time information during congestion will give the road user some peace of mind as they can decide which road to avoid and the best time to travel to get to their destinations easier, faster and safer. Hence, in order to develop an efficient traffic control as well as a good management strategy, it is essential to provide reliable traffic information. Generally, traffic information can be classified into two categories: real time and predictive. Real-time information provides updates on prevailing traffic conditions on streets such as the spot mean speed, link speed or incident information measured or estimated or close to the time of receiving the information. In contrast, the predictive information includes forecasts of traffic flow, speed and travel time between any two desired locations. Recently, the interest in manipulating traffic data is focused on real-time traffic data with the help of the implementation of Intelligent Transportation Systems (ITS) which has resulted in the development of systems that capable of monitoring roadway conditions and disseminating traffic information to travelers in a network. One early example of a real-time project is in Japan where Advanced Traffic Information Service (ATIS) was installed by the Tokyo Metropolitan Police Department to provide graphic traffic information in real time for subscribed home and business offices by using PC communication networks or facsimile networks (Okamoto 1993).

Essentially, traffic information, especially travel time data, may be recorded through a variety of methods. Tuner et al. (1998) discussed several advanced techniques for travel time data collection, including electronic distance-measuring instruments, computerized and video license plate matching, cellular phone tracking, automatic vehicle identification, automatic vehicle location, and video imaging. More commonly, the applicable methods for which the individual traveler is involved to determine the travel time make use of license plate recognition, toll-gates in car systems (Grol et al. 1999) and (Taylor et al. 2000) stated that the measurement methods can be simply divided into two types: logging the passage of vehicles from selected points along a road section (site-based methods) or using moving observation platforms travelling in the traffic stream itself and recording information about their progress (vehicle-based methods). For the first type, the methods include registration plate matching, remote or indirect tracking and input-output methods. D'Este et al (1999) stated that stationary observer techniques include loop detectors, transponders, radio beacons, video surveillance, etc. The site-based methods are capable of collecting information such as vehicle volumes, time mean speeds, headways, classifications, and lane occupancy (Turner and Holdener 1995) .The moving observer methods (vehicle-based methods) include the floating car, volunteer driver and probe vehicle methods. As discussed by Turner et al. (1998), the ITS probe vehicle can be divided into five different approaches: sign-based Transponders, AVI Transponders, Ground-based Radio Navigation, GPS as well as the Cellular Phone Tracking.

The use of available equipment may limit the data collection to one of several techniques. Some agencies have analysis tools that are capable of exploiting certain data collection techniques. For example, agencies with geographic information systems (GIS) capabilities should consider many advantages of GPS data collection. By using GPS probe vehicle, the cost per unit of data may decrease. Conversely, it may increase the availability of the consumer product even though the sample may depend on equipped vehicles only. The most common and useful information that probe vehicles collect is point-to-point travel time (Turner and Holdener 1995). Travel time is selected for the purpose of analysis it is an important piece of information for Intelligent Transport Systems and it is the most common indicator of the quality of a trip. Besides, it is a variable that can be directly measured and simple measure to use for traffic monitoring. The following sections will discuss the probe vehicle technique as a source of travel time data collection used in this research.

2.2. Working principle of probe vehicle for traffic information survey

Using probe vehicles to collect traffic information is one of the potential systems for the effective collection of traffic information in a city where detectors have never been fully activated (Ishizaka et al. 2005). Such vehicles are fitted with equipment for collection of time-stamped location and speed data. Probe vehicle techniques involve the use of a data collection vehicle where an observer records travel time at predefined checkpoints (Okutani and Stephanedes 1984). In case of data collected using Global Positioning Systems (GPS), the exact location of the probe vehicle is captured at specific time intervals. Normally, buses and taxis are used. The number of probes on the network is called the penetration rate and the reliability of the probe data is strongly dependent on the penetration rate.

Respectively, probe vehicles provide data intermittently at locations determined by the location of the probe equipped vehicle and the reporting source. Specifically, probe vehicles will provide travel time for links when they complete traversals of those links (Koppelman et al. 1994). There are several different methods, depending on the technology and driving style. The three most common driving styles are:

i. Average Car – the probe vehicle tries to capture the average of the traffic stream by passing as many vehicles as possible

ii. Chasing Car – the probe vehicle selects one vehicle to be representative of the traffic stream and follows it

iii. Maximum Car – the test vehicle attempts to drive at the posted speed limit unless impeded by traffic

The other common method used to gather traffic information is via traffic detectors. One of the common detectors is the inductive loop detector. A loop detector is a loop of wire that is buried beneath the road surface with a current running through it. The detector provides a continuous stream of volume and occupancy data as well as arrival patterns over a certain time interval at a limited number of locations as it will monitor traffic conditions at single-point locations where the detector is installed. When a vehicle passes over the detector, it persuades a flow of current traffic through the loop. These loops are capable of generating spot mean speed data at various points along a traffic facility. The spot mean speeds must then be processed to estimate the speeds of vehicles between the detector locations. Most studies apply the speed at a detector station to a wider area which is normally half the distance to the next detector. However, there is no guarantee that this represents the average speed over the segment.

Previous studies have discussed these two sources of traffic information in detail. In fact, the expected outputs are not only the summary of traffic data such as average travel time, but also traffic condition estimation and even prediction. Much literature is associated with the use of probe vehicles as well as detectors as a source of traffic information. Kolbl et al. (2002) compared results of motorway performance when using probe vehicle and other motorway flow detection techniques. Travel time was measured using the MIDAS induction system and number plate matching techniques together with probe vehicles on a United Kingdom motorway. Their results showed the influence of the measurement system in terms of counting and headway, travel speed as well as travel time. Linnartz and Westerman (1994) discussed a method of monitoring a metropolitan freeway system using probe vehicles and a random access radio channel in the San Francisco Bay area. In their study, probe vehicles were used to collect real time traffic data and transmitted the data on the same common radio channel. Their results concluded that random access (ALOHA) transmission of traffic reports is an inexpensive and flexible data collection method that can provide accurate real time link travel times and perform Automatic Incident Detection.

Additionally, Cohen et al. (2002) presented the dimensioning of a fleet of probe vehicles on a motorway equipped with a fixed measuring station. Their interests were focused on the probe vehicle sample sizes for travel time estimation on motorways. Yanying and McDonald (2002) proposed link travel time estimation using single GPS equipped probe vehicles. Estimated travel times were calculated by a mathematical model, which combines travel time of probe vehicles and movement characteristics, based on an analysis of speed profile. With increases in the number of road users, there is a need to provide accurate, timely traffic information especially using probe vehicle systems. Taking this situation into account, Ferman et al. (2003) tested the feasibility of such a system using the development of a simple analytical or statistical model. Their results revealed that a real-time traffic information system based on probe vehicles is very feasible, and should work for highways at a penetration rate of over 3%, while surface roads require more than 5%.

Paradoxically, there are also studies that examine the combination of probe vehicle and other sources of traffic information data collection. El-Geneidy and Bertini (2004) studied the optimal spatial resolution for loop detector placement and the optimal temporal resolution for detector data reporting. They used a combination of loop detector and automatic vehicle location (AVL) data from a bus fleet to compare speeds and revealed that the quality of speed data reported by inductive loop defectors using the median speed can be improved by using detectors to represent segment speed during each temporal window. In addition, Cheu et al. (2002) presented a model to provide arterial link speed estimation through combination of data from probe vehicles and loop detectors. The model has been developed, tested and validated with simulated data. Thomas and Dia (2004) also used simulated probe vehicle and loop detector data for incident detection using neural network data fusion.

2.3. Performance of probe vehicle

One of the issues related to probe vehicles is that it is difficult to measure day-to-day variability (Toppen and Wunderlich 2003). In order to measure day-to-day variability, travel time measurements need to be taken across multiple days at the same time. Furthermore, it is not easy to control precisely when the probe vehicles enter the segment for which travel time is measured. The fundamental performance of probe vehicles, such as coverage area and frequency per individual link, depends on the running pattern of vehicles selected as probe vehicles and they would differ by size, network configuration, and so on. Thus, the vehicle, which can collect traffic information efficiently at the lowest possible cost, should be selected as a probe vehicle. But, it is difficult to reveal its performance unless field tests are conducted.

Even though a relatively small number of probe vehicles traveling in the traffic stream can potentially provide valuable information about current travel times, too few probe vehicles can provide erroneous or misleading data, weakening the credibility of the transportation agency and eroding public confidence in the traveler information or traffic management system. Travel time research shows that, the accuracy of travel time prediction can be greatly improved with the increasing density of probe vehicles. However, the accuracy cannot be further improved by adding more probe vehicles beyond a certain density (Ashish et al. 1997). On the other hand, too many probe vehicles on the road might affect the real travel environment.

Table 3. 1 Pros and cons of using probe vehicle technology as compared to detector-based data collection (Turner et al. 1998)

Loop detector systems	Cost of Capital	Cost of Installation	Cost of Data Collection	Data Accuracy	Constrains
Loop detector systems	Low	Moderate	Low	Low	High failure rate and inaccurate estimations
AVI Systems	High	High	Low	High	Probe density and antenna sites

Despite the disadvantages of using probe vehicles for data collection, there are more advantages of using them. Data can be collected over wide areas with a low initial cost for probe vehicles (Toppen and Wunderlich 2003). As the probe vehicles do not require instrumentation to be set up on the roadway, they can easily collect data on any part of the network. Moreover, it requires inexpensive equipment to be installed in the car to collect the data.

2.4. Simulation of traffic environments

Simulation is defined as the dynamic representation of some part of the real world achieved by building a computer model and moving it through time Drew (1968) cited in Pursula (1999). The increased emphasis on simulation studies and the corresponding lack of experience on the part of some people who attempt to apply the method can lead to a type of pseudo simulation. Some rules to follow in avoiding these drawbacks are that: no assumption should be made before its effects are clearly defined, no variables should be combined into a working system unless each one is properly explained and its relationships to the other variables are set and understood and it must be remembered that simplification is desirable but oversimplification can be fatal Drew (1968) cited in Pursula (1999). Transportation systems are typical man-machine systems, where the activities in the system include:

i. human interaction (drivers interact with the vehicle and the elements around them)
ii. man-machine-interactions (drivers interact with the vehicle, traffic information and control systems as well as the physical road and street environment).

Additionally, the laws of interaction are approximate in nature; where the observations and reactions of drivers are governed by human perception and not by technology-based sensor and monitoring systems as reported in Pursula (1999). Figure 2.1 and 2.2 illustrate the basic driver perception-action process and the vehicle object's interactions in a simulation system.

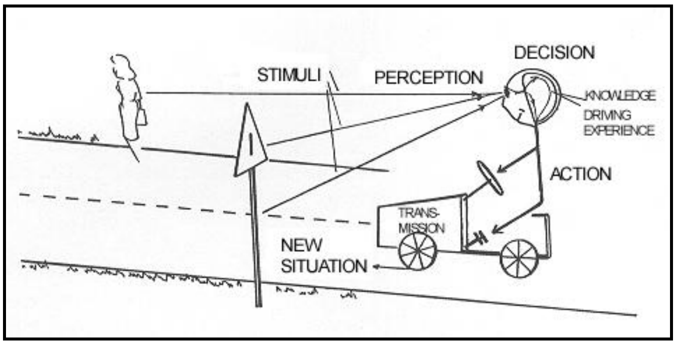


Figure 2. 1 Basic driver perception-action process as in Hakkinen et.al. (1991) cited in Pursula (1999)

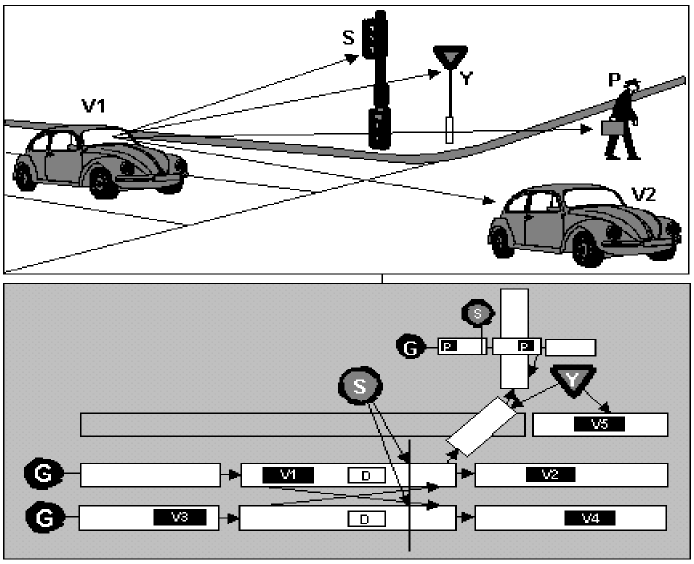


Figure 2. 2 The vehicle-object interactions in a simulation system as in Kosonen (1996) cited in Pursula (1999)

Simulation is a valuable decision-supporting tool for evaluating transportation facilities or systems as reported in Paul and Kevin (1994) cited in Lin (2004). The applications of simulation in the transportation field vary from optimizing the traffic signals at an individual intersection to evaluating the national transport strategy. Transport simulation provides a path for a planner to evaluate their transport designs or strategies through a computer model. Many tests that are difficult to be conducted in real life can be simulated Marcelo (2002) cited in Lin (2004). Today, both computer power and communication techniques have progressed massively. They provide a benefit for modeling with computers as the process of modeling becomes faster and easier than before. Some researchers try to generate traffic data from simulators to do their research as simulation has the ability to trace entities through a system of multiple processes and operations (Anderson and Bell 1997). However, even though using the simulation, particularly micro simulation, is a useful tool to be treated with respect, it is easy to draw the wrong conclusions if the developer is not fully familiar with the model (Brunner et al. 1998). Traffic planners and engineers are conservative by nature, and many of them view micro simulation with doubt. Some consider it as a radical approach with insufficient integrity, thus continue to struggle with systems designed to address issues of an earlier age (Druitt 2000). On the other hand, practitioners and clients, who have used micro simulation software for analysis, have been highly satisfied with the outcomes.

In micro simulation, the term “micro” applied to traffic models of individual junctions or small confined networks (Pursula 1999). Traffic relates to movement or number of vehicles. In the dictionary, the definition of simulation is to reproduce in order to conduct an experiment or to imitate. Therefore, the full explanation of microscopic traffic simulation is a reproduction of events to imitate the movement of individual vehicles along a road network. In the past, few micro simulation studies of emergency evacuation procedures have been documented in the literature especially before the 1990s. The lack of micro simulation procedures was largely due to the fact that modeling traffic flows at the individual vehicle level is a computationally challenging task, and there were inadequate computer technology and advanced software engineering to easily simulate the complexity of traffic flow involving a large number of vehicles. Previously, “microscopic simulation” or “micro simulation” has been limited to small areas because of high computational demands, however, recent advances in both hardware and software are now making this accuracy available for all sizes of models. Moreover, nowadays, some software allows users to visualize the progress of vehicles along the road network while the simulation is running.

2.5. The Utilization of micro simulation in traffic information surveys

In order to yield useful traffic information, several analytical techniques can be employed. Basically the expected outputs are not only the summary of traffic data (e.g. average travel time), but also traffic condition estimation and even prediction. The estimation requires not only the raw traffic data, but the understanding of traffic flow, condition, and relationship versus time. To yield more accurate traffic information, the manipulation of traffic data needs to be examined. Several methods are possible, ranging from statistical updating to simulation exercises. Recently, the simulation method is widely used since the analysis of simulation data has given us a clear view how travel times are temporally and spatially correlated. Therefore, in consequence of the need of demonstrating the potential impact of the probe vehicle on manipulating travel time information, a computer simulation model will then be applied.

In this study, a micro simulation technique was used to generate artificial data for the analysis since we face difficulties in gathering the real data. The reason why micro simulation models have been accepted is because they can consider dynamic running patterns of each vehicle (Ishizaka et al. 2005). Some previous research studies used traffic simulators, such as Vissim, to generate pseudo–detector data (Anderson and Bell 1997). Various simulations were set up (Ivan et al. (1994-1998)) cited in Lin (2004) to collect both probe and loop detector data. A micro simulation model was used to estimate the minimum number of probe vehicles (Chen and Chien 2000). Nevertheless, since their network consisted of only one freeway with 5 intersections, the dynamic distribution of probe vehicles was not considered. There was also a study using the micro simulation model for the road network of the Clemeti town area in Singapore (Cheu et al. 2002). Taylor et al. (2002) combined the micro simulation modeling and probe vehicles for a traffic study. They used the model to analyze the performance of the corridor when an incident occurred in terms of traffic condition and gas emissions. The micro simulation software, Paramics was used to allow a representation of the probe vehicles in the network.

Other research works dealt with micro simulation in examining traffic data. For example, Sisiopiku and Rouphail (1994) studied the performance of arterial travel time estimation by examining the use of detector output from simulation and field studies. They bridged the gap between arterial travel time and flow and occupancy data in order to create an alternative source of travel time information. These travel time data can then be used in a data fusion process expected to take place within the framework of Advanced Traveler Information Systems (ATIS). Data fusion is a function that combines travel time data from various sources (on-line or off-line) to produce reliable estimates of travel time for route guidance applications. In addition, Inokuchi et al. (2003) developed a simulation system that is corrected using on-line data to raise the accuracy of the simulation. The simulation system was developed by using the microscopic road traffic simulation system CaTS (Car-following-based Traffic Simulation) and applied to the Hongo area, Japan. In the study, since no on-line data were obtained, it was executed using virtual on-line data, and the usefulness was shown.

VISSIM, a German acronym for “traffic in towns – simulation,” is a stochastic microscopic simulation model developed by Planung Transport Verkher (PTV), a German company. It is a time-step and behavior-based simulation model developed to model urban traffic and public transit operations. The model consists internally of two components that communicate through an interface. The first one is the traffic simulator, which is a microscopic traffic flow model that simulates the movement of vehicles and generates the corresponding output. The second component, named as the signal state generator, updates the signal status for the following simulation step. It determines the signal status using the detector information from the traffic simulator on a discrete time-step basis (varies from 1 to 10 steps per second), and passes the status back to the traffic simulator.

The inputs in VISSIM include lane assignments and geometries, demands based on origin-destination (OD) matrices or flow rates and turning percentages by different vehicle types, distributions of vehicle speeds, acceleration and deceleration, and signal control timing plans. Signal control can be fixed, actuated or adaptive control using VAP. The model is capable of producing measures of effectiveness commonly used in the traffic engineering profession like total delay, stopped-time delay, stops, queue lengths, fuel emissions, and fuel consumption. The model has been successfully applied as a useful tool in a variety of transportation projects such as development and evaluation of transit signal priority logic, the evaluation and optimization of traffic operations in a combined network of coordinated and actuated traffic signals, and an analysis of slow speed weaving and merging areas. VISSIM 5.0 was used in this study due to its excellent graphical capabilities. Besides, the coding of roadway networks within VISSIM is rather different from most other traffic simulation models.

CORSIM and SimTraffic, for example, rely on series of links and nodes to form roadway networks, in contrast to VISSIM's link-and-connector approach. The approach that VISSIM has allows for greater flexibility when compared to the other models.

Chapter 3

Presentation styles of traffic information and driver behavior

3.1. Channels of information dissemination

Within the last few decades traffic congestion has become a major concern of the cities worldwide. Due to growing urban sprawl and suburbs, excessive congestion problem has propagated from cities to its outskirts and rural areas. Mobile societies are associated with a higher number of cars on the street and higher rate of accidents which is also responsible for the critical route situation. Consequently, existing road networks are overloaded with user demand and travel delays are seen as commonplace. Governments spotted that traffic affects not only quality of life but also contributes to environment condition. These realizations triggered the research in the field of increasing mobility on the roads. The term Intelligent Transportation Systems (ITS) has gained extraordinary value, put pressure and set development directions for tackling traffic congestion issue. From technological point of view, one of the ITS responsibility is to deliver actual road condition information. Technologies such as car navigation, traffic signal control system, and more advanced methods of integrating live data and feedback coming from different sources i.e. parking guidance or weather information and so on has a high value of helping minimizing traffic congestion.

But why do we need all these? It is believed that spreading traffic information will let drivers make smarter travel choices which may lead to the congestion cut. For instance, providing drivers with information on travel time delays on particular routes may encourage them to change the attributes of their journey including time departure, route, mode, destination or even whether to think about not making trip at all. Traffic information assistance may also serve as tool for environmental protection suggesting routes away from environmentally sensitive areas.

A number of information dissemination modes or tools are currently employed to provide drivers with traffic information. The information include incident, congestion, construction, weather and many more. The aims of these tools are to inform drivers of traffic conditions and ensure safe, comfortable and smooth driving. Advanced Traveler Information Systems (ATIS) provide real time travel information with respect to traffic conditions. ATIS have significant potential to enhance driver’s mobility and are expected to assist drivers’ route choice process including pre-trip (departure time, route planning) and en-route trip decisions (such as congestion or incident avoidance, destination choice and route selection). For transport authorities, ATIS are also very beneficial because they can be used as traffic management systems to improve road network performance.

There are many ways in which ATIS have been implemented internationally and Table 3.1 shows the current state of implementation in Australia, Japan, USA, United Kingdom and other countries as reported in Furusawa (2004).

Table 3.1 ATIS projects around the world as summarized in Furusawa (2004)

Country	Area	Organization	VMS	Web	Radio	Tel	Comments
UK	London	Greater London Authorities	O	O	C	O	Real time traffic information (VMS, Web, Telephone) Incidents, Roadworks http://www.london.gov.uk/
	All areas in UK	Highways Agency	O	O	C	O	Real time traffic information (VMS, Web, Telephone) Incidents, speed and lane strictions (VMS) Delay time (categorized as: No delay, 15-30 min delay, and Over 30 min delay), current incidents, roadworks and provided messages on VMS (Web) http://www.highways.gov.uk
	Nottingham	Nottingham Travel wise Service		O	C		Real time traffic information (Web) Incidents, congestion table, planned works and events http://www.itsnottingham.info/
	Southampton	ROMANSE (Partnership between Hampshire County Council and Southampton and Portsmouth City Councils)	O	O	C		Real time traffic information (VMS, Web) Three types of VMS are installed: Route Guidance VMS, Car Park VMS and Mobile VMS On-line website provides travel news including incident information, car park occupancies and CCTV images http://www.romanse.org.uk/
	South Wales	Traffic Wales		O			Real time traffic information (Web) Current network status, traffic map based traffic flow, Roadworks advice, incident status, trave time estimates and E-mail and SMS automatic Notification http://www.traffic-wales.com/
UK	All areas in UK	BBC			O		Traffic information (comprehensive information) Source is provided by transport authorities http://www.bbc.co.uk/
	All areas in UK	AA, RAC (Road Service Unit)		O			Traffic information (Incident information) Source is provided by transport authorities http://www.theaa.com/ http://www.rac.co.uk/
Others	Germany Switzerland Austria Italy Netherlands Belgium		O	O	O		There are many other countries providing real time traffic information on web sites.

	France Moscow Finland Singapore Taiwan Korea Greece						
USA	San Antonio	TxDOT-San An (Texas Department of Transportation)	O	O			Real time traffic information (VMS, Web) Travel time, traffic conditions http://www.transguide.dot.state.tx.us/
	Los Angeles	LADOT		O			Real time traffic information (Web) Traffic congestion, travel speed http://www.ci.la.ca.us/LADOT/
	Houston	Houston TranStar	O	O	O		Real time traffic information (VMS, Web) Travel time, traffic conditions - Historical traffic information (Web) Historical speed map, historical travel time http://traffic.tamu.edu/
	Boston	The Boston Blobe (Newspaper)		O			Current traffic conditions (Web) http://www.boston.com/traffic/
	Gary, Chicago and Milwaukee	GCM travel	O	O			Real time traffic information (Web) Travel time, traffic conditions http://www.gcmtravel.com/gcm/home.jsp
	Maryland	CHART (Coordinated Highways Action Response Team)	O	O	O	O	Real time traffic information (VMS, Web, Radio, Telephone) Travel time, traffic conditions - Traffic information by media (Radio, TV) http://www.chart.state.md.us/
O Available ATIS tools for providing with real time information C Radio information used to be used in certain locations							

ATIS tools are categorized into two phases related to the driver's travel situation, namely: pre-trip information and on-trip information which basically provides enroute information. Below are the examples and the phases they cater for.

- Television

Television belongs to the primary sources of pre-trip traffic information. Traffic reports may be provided during local news broadcasts, as special reports during major events such as extreme weather, or continuously through a dedicated traffic channel.

- Radio

The Traffic Message Channel (TMC) is a technology for delivering traffic and travel information to drivers. It is typically digitally coded using the FM-RDS system on conventional FM radio broadcasts. It can also be transmitted on Digital Audio Broadcasting (DAB) or satellite radio. It allows silent delivery of accurate, timely and relevant information, in the language chosen by the user and without interrupting normal services. Services, both public and commercial, are now operational in many countries worldwide. When data is integrated directly into a navigation system, this gives the driver the option to take alternative routes to avoid traffic incidents. The traffic information is typically sourced from the police, traffic cameras, loops and probe vehicles

- Internet

Web-based traffic information can be provided in a number of formats through a variety of information providers. Government-operated websites may provide direct access to primary traffic, incident, and weather information. Websites for local media outlets may also provide traffic information, whether obtained directly from a government source or through a third party ISP who collect and integrates their own information from sources such as incident reports, traffic cameras, and aerial surveillance. ISPs may also operate their own independent websites. Information can be provided in text or graphical formats.

- In-vehicle Information system

This type of information includes include mobile phones and other on board devices such as GPS navigation system as well as Vehicle Information and Communication System (VICS). Figure 3.1 and Figure 3.2 illustrates the example of in vehicle information system.

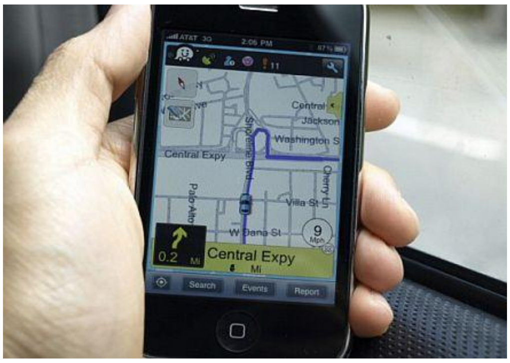


Figure 3. 1 I-Phone and a real-time traffic mapping application

Figure 3. 2 GPS device as an example of an on-board device for traffic information

- Stationary devices such as Variable Message Sign (VMS)

Variable Message Sign (VMS) can display many kinds of messages which traffic management organizations wish to make known. Nowadays, there are several types of VMS such as travel time information boards and graphic signboards as in Figure 3. 3.

Figure 3. 3 Examples of Variable Message Signs

3.2. Presentation styles of traffic information

As discussed previously, traffic information can be received via multiple channels. The information can also be categorized into two different groups which are information received in the vehicle and information using stationary devices located on the road. Both are intended as on-trip information. The disseminated information includes the traffic information in real time or offline. Much research work has been dedicated to the discussion of these platforms. One example of web-based visualization was discussed in Lu et al. (2006) where an Advanced Interactive Traffic Visualization System (AITVS), a web-based traffic visualization system was created. The purpose was to help mitigate the very concerns by providing novel and comprehensive visualization components to analyze and monitor traffic conditions. Goldsberry (2005) evaluated the common problems associated with traffic maps using two design criteria which are the cartographic quality of real-time traffic displays and the quality of the dynamic human-map user interface. Variable Message Signs (VMS), also called Changeable Message Signs (CMS), Dynamic Message Signs (DMS), or Electronic Message Signs (EMS), are also used broadly. These devices are usually installed along the roadside to display special event messages and serve as basic tools of the Traffic Management Center (ATMC). They can be manufactured with low cost and are used for transferring only text and graphics giving a strong impression with red, green, and yellow colors. Some of these channels of information use numbers or text on VMS, some are map-based or graphics-based and others use SMS or radio traffic reports. In graphic information, symbols or maps are used. They are very attractive for the user to see and to understand the information. Japan has implemented this type of information for some time and in Europe (such as in Netherlands and Germany), the concept of having graphics-based information has becoming more popular (Richards et al. 2005). Figure 3.4 to 3.7 depicted some of the graphical based information.

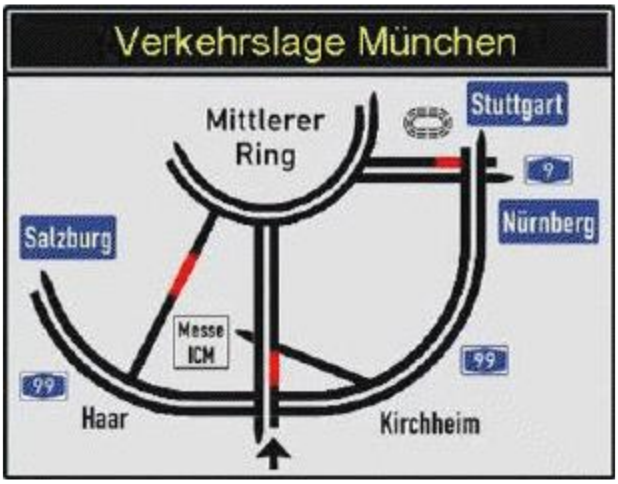


Figure 3. 4 German Grip Panel

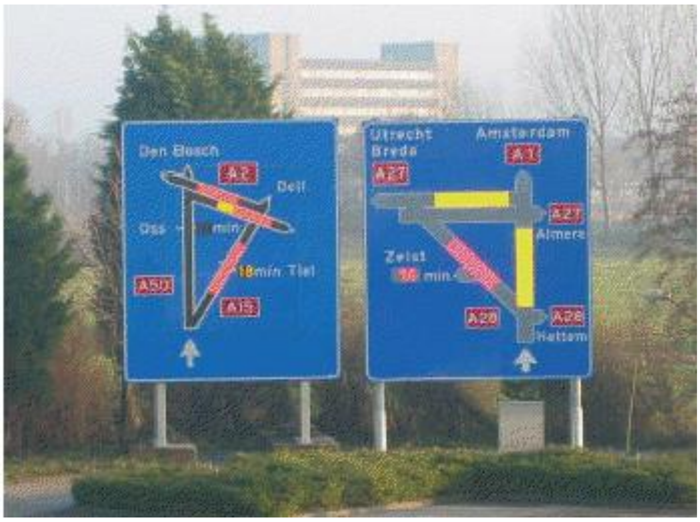


Figure 3. 5 Netherlands Grip Panel

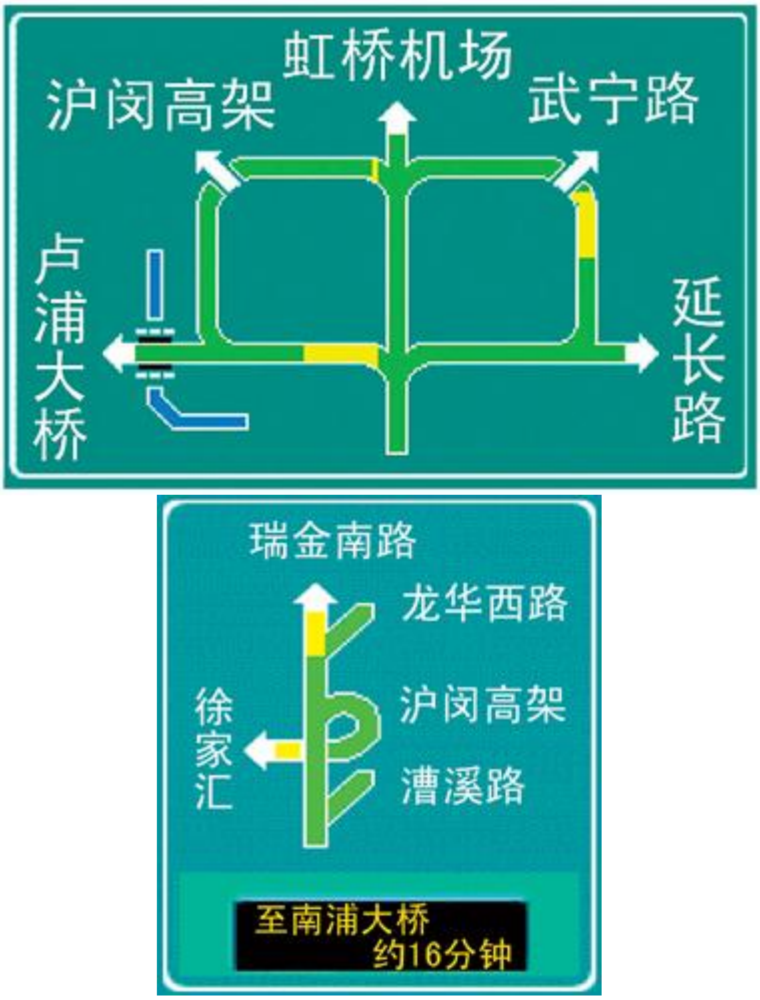


Figure 3. 6 Chinese GRIP Panel (Shanghai)

Figure 3. 7 Australian Grip panel

In Germany (Munich), Schönfeld et al. (2000) has reported extensive research work that aimed to obtain a better panel design for GRIP. The German GRIP uses red to indicate delays (Figure 3.4). A black default setting may be changed to red according to congestion levels. Dicke-Ogenia et al. (2008) reported studies for the Netherlands GRIP, a black default setting may be changed to yellow and red according to congestion levels as in Figure 3.5. Gan (2010) had discussed color-coded level-of-service (LOS) map and route travel time displayed by GRIP (Figure 3.6) for a Shanghai urban freeway. This paper focused on graphical information methods together with a discussion to propose a traffic flow model based travel time prediction approach for the GRIP panel. In addition, Kloot (1999) has reported road signs with color strips used in Australia to measure the level of congestion between roadway sections which used a three-color scheme of green (light traffic), yellow (moderate congestion) and red (heavy congestion) as in Figure 3.7.

The visual presentation of the information plays an important role in the process of understanding large and complex data sets. Hughes (2004) mentioned that the effectiveness of visual presentation should not only depend on the technologies but also on the applications. Studies of the measurement of the visual behavior of participants (considered a physiological measure) always refer to as efficiency of looking for information. It is important to make sure that the road user can receive and interpret the information in a more effective and efficient way. Taking into account the importance of evaluating the system towards minimizing the level of congestion, Lavalette et al. (2007) initiated research aimed at explaining the reasons why some people behave differently towards the Variable Message Sign (VMS) system. Bierlaire et al. (2006) analyzed driver response to real-time information in Switzerland. A behavioral model was designed to analyze driver decisions when traffic information was provided during their trip by the radio data system and VMS. Khattak et al. (2003) reported that information source, information contents and information attributes are the factors affecting traveler response to Advanced Traveler Information Systems (ATIS). The information source leads to the expectation of people to have different levels of access and use the information device in different ways while the information content may focus on both qualitative and quantitative measures. The information attributes are likely to influence the decision making if it is perceived as credible, relevant and accurate.

In relation to visual information, systems can present information using graphics, symbols or even written messages (Ross and Burnett 2001). Some systems display maps in two or three dimensions (2D or 3D). Other commonly used devices present information by means of symbolic messages, for example using arrows, to indicate each turn or maneuver that the driver has to perform and can also display other information such as the distance to the next turn and the names of the streets. They are included in the “Route Guidance Systems” category and can be commonly named as “Turn-by-turn” systems.

Garrick et al. (2005) reported that geographic information systems (GIS) and traffic simulation have attracted much attention for visual representation in transportation. They identified seven major categories of visualization techniques in the transportation field: artist concept and rendering, image composite, video overlay, computer animation, video, geographic information system and traffic simulation. Visual realism, geometry accuracy, production effort, training and cost are the factors that contribute to the effectiveness of the visualization.

Table 3.2 Characteristics of visualization techniques as in Garrick et al. (2005)

Visualization techniques	Visual realism	Geometry accuracy	Production effort	Cost effectives	Output format
Artist’s Concept	Low-Med	Low	Moderate	High	Slide
Image Composite	High	Low-High	Moderate	High	Slide
Video overlay	Med-High	Low-High	Moderate	High	Video
Video	Med-High	Low-High	Moderate	High	Video
Computer animation	Low-Med	High		Low	Video
GIS	High	High	Moderate	Moderate	Slide
Traffic simulation	Low-Med	Low-Med	Moderate	Moderate	Video

Pack (2010) had presented a high level introduction to current visual information research for transportation. He had also discussed research opportunities which also cover transportation data visualization, wide-area real-time simulation, visualizing and mining archived data, massively multiplayer on-line games (MMOGs), and even virtual design and construction. The presented designs are basically for the visual view of traffic management center (TMC). One of the examples is as Figure 3. 8, a screenshot of a system which interacts with traffic databases to show animations of traffic, incident and weather data.

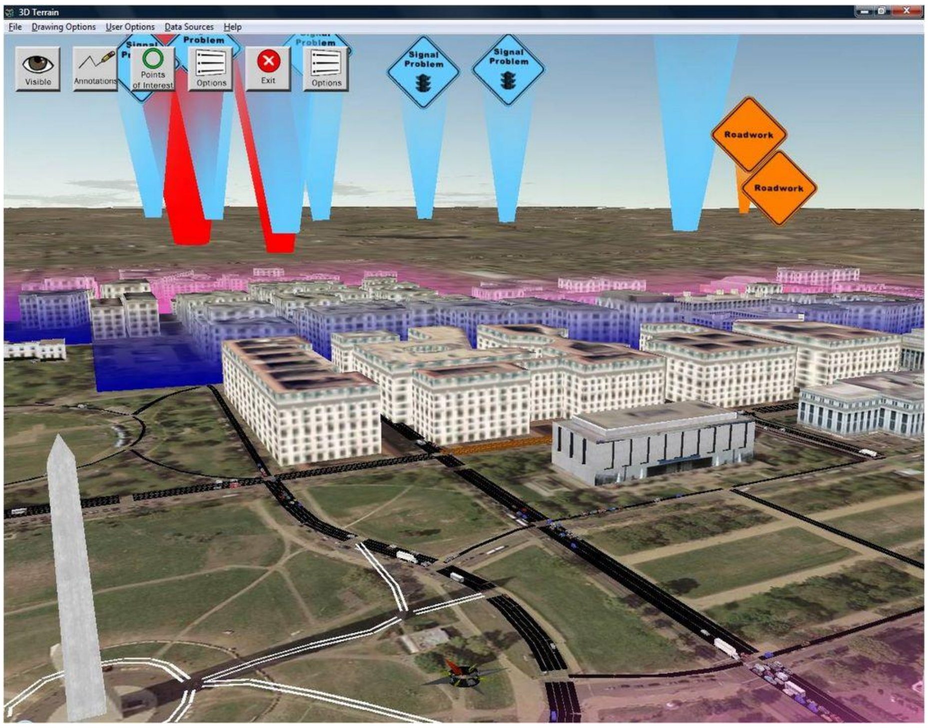


Figure 3. 8 4D real time visualization systems displaying traffic conditions on a wide scale

The overwhelming majority of traffic information sources provide real-time traffic information, helping drivers to make informed decisions on choosing a correct traffic route on the basis of current traffic conditions. However, these presentations are seldom designed from the perspectives of the drivers themselves. Existing traffic information presentation styles sometimes contain information that does not make information easily readable and comprehensible. Although the potential benefits of providing traffic information have been established, there is still a lack of effectiveness in providing traffic information to the drivers. There is disagreement about what is more important, content or presentation style. Some researchers say ‘content is a king’ yet others say content is essential and presentation an afterthought. Information processing such as mental activities including recognizing, rehearsing, planning, understanding, decision making and problem solving occur in working memory (Brookhuis and Dicke 2009). While traffic information can be provided using both visual and auditory means, it is essential to have knowledge of the limitations and possibilities of the information processing system. A disruption in performance when two tasks are executed concurrently as well as little interference when two concurrent tasks entail information from different modalities can happen with this limited processing capacity (Brookhuis and Dicke 2009).

Albert Einstein cited in Garrick et al. (2005) provides his understanding of visual perception: "If we trace out what we behold and experience through the language of logic we are doing science; if we show it in forms whose interrelationships are not accessible to our conscious thought but are intuitively recognized as meaningful, we are doing art". Thus, there is a need to use a meaningful solution to represent information in a more valuable way. A picture is often cited to be worth a thousand words and, for some tasks it is clear that a visual presentation such as map is dramatically easier to use than other textual or spoken descriptions.

Visual displays become even more attractive to provide orientation or context, to enable selection of regions and to provide dynamic feedback for identifying change such as dynamic traffic congestion map. Therefore, it is vital to understand the relationships between visual perception (the message received by the viewer) and the visual stimuli (the product of visual techniques). Having this knowledge will permit more effective communication at a fundamental level. It is reported that 90% of information input in driving depends on the visual channel (Noguchi as cited in Akamatsu et al. (1997)) and due to this fact, the measurement of visual performance is important in the analysis and evaluation of human interactions. The interaction with displayed information can lead to driver distraction due to the allocation of their visual resources. For example, the longer the driver looks away from the road, the more likely they will miss some critical safety information from the road environment. Mannering et al. (1995) had reported interesting results where 34.05% of their respondents believed the type of visual display is very important. Even though they had stated this percentage seems rather low, the use of a visual display that is undesirable could still result in the loss of over one third of the market, which is likely to have a dramatic impact on technology acceptance and profitability. A lucid explanation of visual information gathering has been discussed in Lim et al. (2004) where it was concluded that a key step to the better understanding of the driver is to understand the visual information acquisition process of the driver. The driver generally requires the use of only three of his or her five physical senses, namely visual, auditory, and vestibular, and of these three, the most important without a doubt is the visual perception.

Pauzie and Marin-Lamellet (1989) stated that drivers reduce their average glance time on the central road when using a visual display. This is especially true for older drivers. On the other hand, age was found to be statistically significant in push-button performance, navigation performance, subjective workload ratings and driving performance as discussed in Liu (2000). These findings that related to the use of in-vehicle devices have led to conclusions that the older drivers performed worse than the younger drivers. In addition, older subjects using the visual display had longer reaction times and a larger number of missed button pushes.

The information to be presented is the input of a visual system. This information could vary a great deal from one system to another. To formulate general rules that help to map the information to visual discourse, we must understand presentation-related properties that are common to all information where two modalities can define the way inputs reach the subject.

It can be done in a visual or in an auditory manner. However, the use of a traffic information system while driving will require time sharing between multiple tasks. Experience showed that people can sometimes divide attention between what they have seen and what they have heard. This is done in a more effective way than dividing attention between two auditory messages or between two visual inputs. The Multiple Resource model (Figure 3.9) assumes that there are three limited capacity resources: processing stages (ranging from early perceptual to late central processing), modality (auditory and visual) and response (spatial and verbal). Optimal task performance is achieved when the conflict between the resources required for each task is minimized. Individuals have to adapt to relatively independent pools of attention resources for the processing of visual and auditory stimuli. This theory provides a basis for current concerns over driver's ability to successfully interact with information whilst driving which had been implemented in the study of Anttila and Luoma (2005) and Hamish Jamson and Merat (2005). They analyzed the potential distraction on an in-vehicle information system on driving performance.

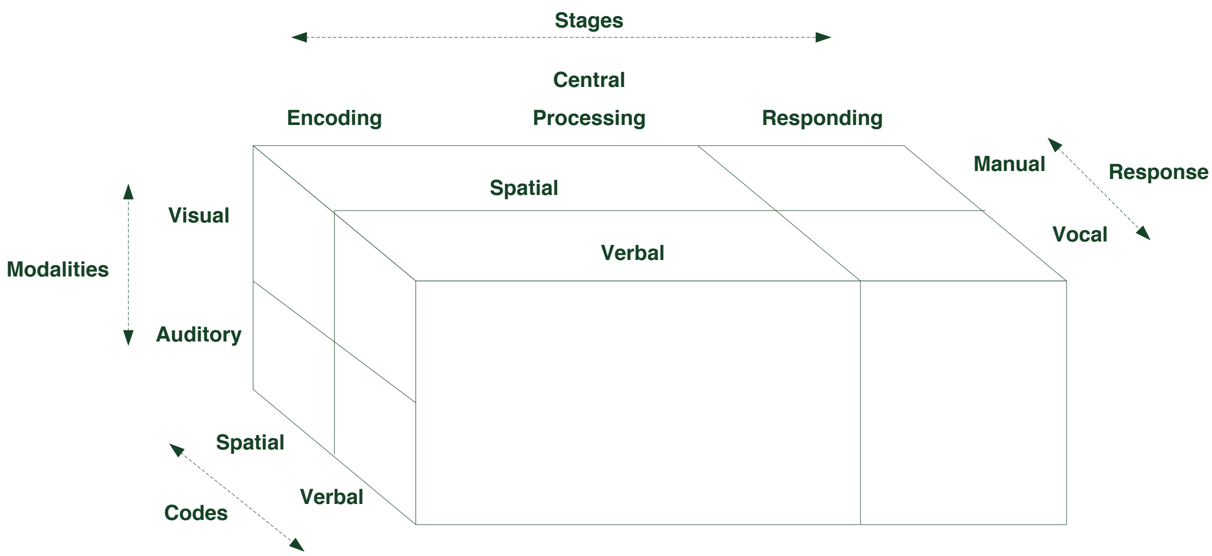


Figure 3. 9 Structure of the multiple-resource model of attention Wickens (1984)

The other interesting aspect that can contribute to augment the knowledge regarding the behavior of drivers is the analysis of male and female participants. As different genders can have distinct attitudes towards the new technologies, opinions regarding its utilization as well as their behavior can be different while interacting with such products. Mannering et al. (1995) stated that gender findings are interesting because men found traffic information less important but, apparently, if such information is provided, they prefer to have it far in advance. This statement seems to suggest some skepticism among men with regard to the usefulness of the technologies. Their desire to have the information far in advance will presumably provide them greater flexibility in evaluating the usefulness and validity of such information. This is likely due to the differences in driving experiences between men and women or it could reflect an attitude/resistance among males to accept information or overconfidence in their ability to select the best route.

3.3. GIS as the supporting tool

Several tools are available for visualizing information. The use of Geographic Information Systems (GIS) as a visualization tool has become more and more popular in the field of transportation. A Geographic Information System (GIS) is an automated information system that is able to compile, store, retrieve, analyze, and display spatial data. The existing maps, aerial photos, satellites, and other sources are the main source of data in GIS. A GIS displays actual geographic or mapped objects, however, it is also powerful for analyzing data and presenting the results of that analysis as useful information to assist decision makers. GIS acts as a platform for viewing and analyzing traffic information for improving accuracy and to assess the effectiveness of traffic information display. With the implementation of GIS to display actual geographic or mapped objects, the traffic information can be sent easily in real time. GIS can be used in two ways, for data collection as well as for displaying traffic information.

As indicated by Taylor et al. (2000), transportation data is usually associated with spatial data, such as traffic counts from particular sites, the traffic volumes along particular roads or links. GIS can be used as a database for storing transportation data. The primary advantage of using GIS as a database for transportation data is the fact that GIS can integrate the spatial data and display the attribute data in a user-chosen format. GIS is a tool for linking and visualizing geographically referenced information using topological (geographical) and attribute data sources. GIS can also be used to predict traffic accidents and model traffic accident risk, which can have a direct impact on policy and planning.

Research works associated with the use of GIS are widely spread both in transportation planning and traffic engineering. Chen et al (2006) reviewed existing transportation GIS applications and research perspectives and proposed a preliminary framework for an integrated GIS for the city of Guangzhou by taking into account the existing applications and demands as well as the problems raised. Claramunt et. al (2000) set up a framework for the integration, analysis and visualization of urban traffic data within geographic information systems. Their research explored some experimental methods for the real-time integration (i.e., preprocessing), manipulation, visualization and animation of dynamic phenomena within VDGIS. The presented framework has illustrated and validated some context of a VDGIS for a real-time traffic system. This method proposed the implementation with the prototype OSIRIS as the proposed architecture that combines a dynamic integration of traffic data, pre-processing of traffic data at complementary levels of granularity, the integration of temporal operations within a GIS query language, and acts an interface that supports visualizations and animations in the thematic, spatial and temporal dimensions.

Rao et al (2005) explored the Intelligent Traffic Guidance and Monitoring System (ITGS) under GIS environment. They used the Dynamic ITGS which promotes online monitoring of traffic mobility, equilibrium conditions of dynamic (vehicular) characteristics and static (network) features. Their study concluded that the Dynamic ITGS is a suitable configuration to address many traffic field problems of developing countries where this system not only identifies the problem but also addresses the solution. Moreover, it also monitors the vehicle movements, helps to promote pollution free, economic and congestion free travel. In addition, Byon et al. (2006) developed GISTT (GPS-GIS Integrated System for Travel Time Surveys), a system for link travel time estimation, including static estimation for planning purposes and dynamic estimation for ITS applications. Their results revealed that the Dynamic GISTT provides information of probe vehicles in real time that matched to certain links. Nevertheless, this means that there is no information associated with links where probe vehicles did not travel recently. Travel times can be estimated from results of previous travel time studies using Static GISTT for those links that lack recent information. On the other hand, the real-time data from probe vehicles can be archived for future Static GISTT analysis as well. Additionally, GISTT can also provide second-by-second position, speed and acceleration information which then can be used for emission and pollution analysis on the existing road network. GISTT can also be integrated with other existing monitoring or data collection tools such as loop detectors or traffic video cameras on highways. GISTT can be applied to transit vehicles by correlating the general traffic attributes with those of transit vehicles in the static mode.

Hartman, D. and P. Herout (2000) reported the implementation results of a traffic simulation model based on head leading algorithm in collaboration with the city of Pilsen on a complex system. The aim for this study was to create a complex simulation system for urban traffic that should be highly configurable and easy to use. Their effort was inspired by the demands of the Pilsen city traffic control where they only have an analytical tool for analyzing fluctuations of traffic flows in specific areas and they were interested in the development of microscopic model to achieve width applicability. Data such as road network were obtained as layers from Geographic Information System (GIS).

El-Geneidy, A. and R. L. Bertini (2004) integrated a Geographical Information System (GIS) and an Intelligent Transport System (ITS) to improve incident management and safety. They highlighted the power of an existing GIS-T data model by using a highway incident data model. The presentation of incidents (e.g. accidents and breakdowns) as event points on transportation features led to the definition of high incident severity and duration highway segments. Their results showed that the 3D visualization and the raster modeling were not sufficient for the application to highlight segments as high priority locations for the incident response program in Portland, Oregon. However, they represented a good way to explore the data before starting detailed analysis. The use of GIS-T and ITS data have shown that if the transportation data is archived properly, GIS can be a useful tool. Wang (2005) proposed an idea to integrate GIS, simulation models, and visualization in traffic impact analysis. His study demonstrated that such integration could improve the efficiency and accuracy of simulation models and present modeling results in a more understandable visual fashion. Moreover, Zhou et al. (2006) introduced an application framework for implementing Real-Time Traffic Information Applications (RTIA). The integration of the Real-Time Traffic Simulation Systems (RTSS) with RTIA, using RTSS as the data source to replace the real-time detector data was developed. Furthermore, a web-based Geographic Information System for Transportation (GIS-T) architecture, combined with the temporal-spatial database was used and this combination provides a flexible way to represent the real-time traffic information for road users.

Taylor et al. (2002) developed an integrated Global Positioning System (GPS) and Geographical Information System (GIS) for collecting on-road traffic data such as travel time, delay, and congestion data from a probe vehicle whereas Fiet et al. (2005) presented a method on acquiring several traffic data from different data sources, such as induction loop sensor data (vehicle volume, average flow speed, road occupancy), traffic monitoring video camera images, position data of the public transport vehicles and cabs, digital database of road construction areas. A technique to combine and analyze them in sophisticated GIS (Geographic Information System) environment was also presented. Alternatively, Tong et al. (2005) described a method of extracting transportation information using global positioning system (GPS) receivers integrated with geographic information system (GIS) technology. The results of GPS data compared favorably with the corresponding loop detector data.

3.4. Color-based congestion indicator

Bertin (1967/1963) as cited in MacEachren (2004) proposed seven fundamental visual variables include geographic position in the plane (X-Y location), size, (color) value, texture, color (hue), orientation and shape as depicted in Figure 3.10.

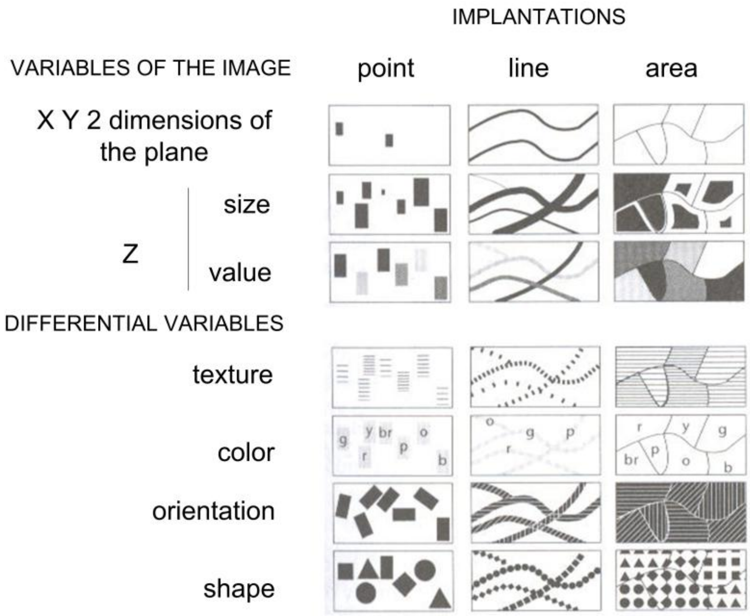


Figure 3. 10 Bertin’s graphic variables as in MacEachren (2004) page 271

Bertin also proposed rules for the appropriate use of visual variables. Three different categories were defined which include whether or not it is appropriate for depicting quantitative information (numerical), ordered information and nominal information. Figure 3.11 shows the standard interpretations of Bertin’s contentions of his visual variables.

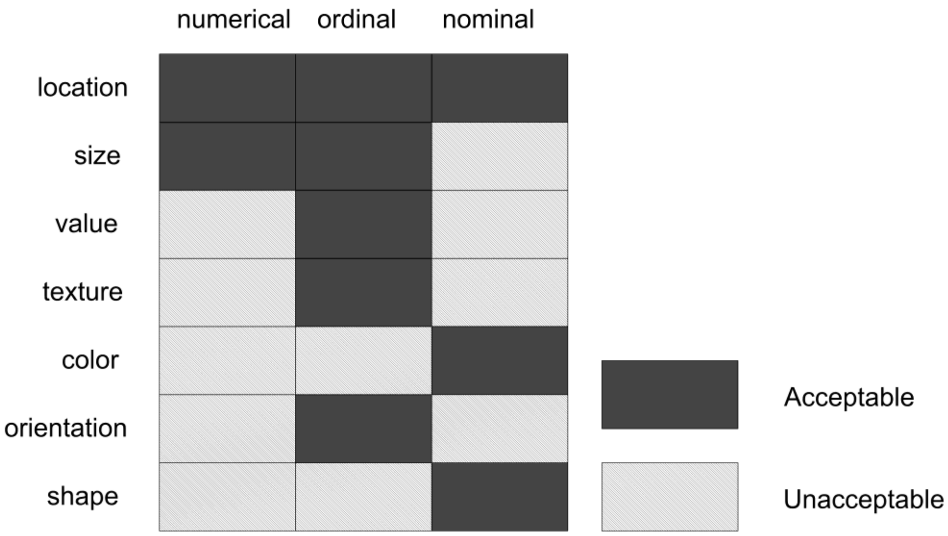


Figure 3. 11 Bertin’s graphic variable syntactics which relates to the level of measurement to graphic variable as in MacEachren (2004) page 272

As depicted in Figure 3.10 and 3.11, one important consideration for graphic is the color. Issues such as developing audience participation and effective use of colors and images are extremely important (Garrick et al. 2005). As a property of preconscious vision, color is one of the most powerful visual properties in visual presentation. When using color to represent data, each value or range of values of data is transformed to be associated with a color. The correct use of color can be a great aid to the understanding of information in visualization presentation. However, in many instances, misuse of color can lead to serious misinterpretation of data. For example, the same data viewed as an image looks different depending upon both the color map and the transformation function (linear or logarithmic) employed to map them onto the color space. The properties of color that are inherently distinguishable by the human eye are hue, brightness and saturation. Figure 3.12 is an example showing color bands of hue, brightness and saturation, respectively. This figure shows that hue is described by its wavelength: red at the left end of the visible spectrum and violet at the other end. Brightness corresponds to how much light appears to be reflected from a surface in relation to nearby surfaces. No brightness will appear as black. Saturation represents the purity of color -- the amount of white mixed in with a pure color. If white is added to a given hue, saturation will be decreased. In other words, no saturation will appear as white. In this example, the pink color in the middle can be thought of as having the same hue as red but being less saturated.

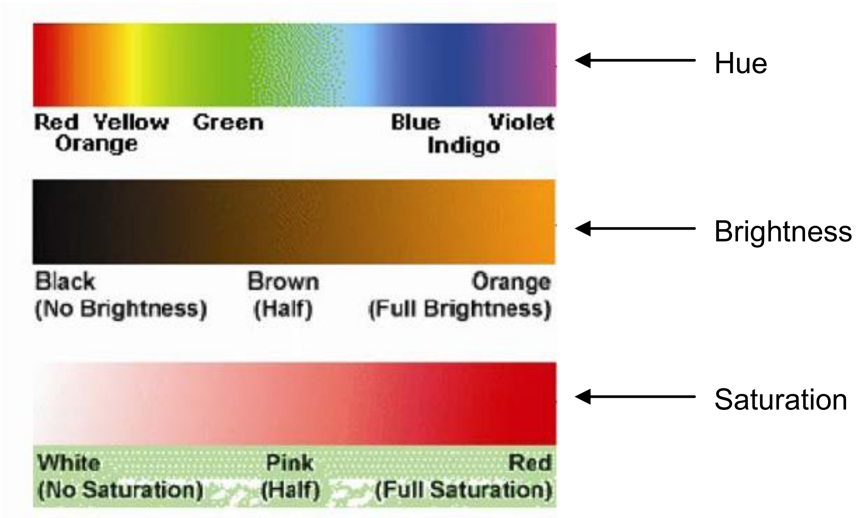


Figure 3. 12 Example of Hue, Brightness and Saturation as in Garrick et al. (2005)

Color and shape are dominant visual features of traffic signs with distinguishing characteristics and contain key information for drivers to process when driving along the road. Therefore to develop a driver assistant system for recognition of traffic signs, this information should be utilized effectively and efficiently even in the knowledge that color and shape vary with the change of lighting conditions and viewing angles. Color is regulated not only for the traffic sign category (red = stop, yellow = danger, etc.) but also for the tint of the paint that covers the sign, which should correspond, within a given tolerance, to a specific wavelength in the visible spectrum. However, most color-based techniques of communicating information run into problems if the color combination is incorrectly matched.

Table 3. 3 The user acceptance for different schema of color indication (Campbell et al. 1998)

'Green' is often used for information such as	'Yellow' is often used for information such as	'Red' is often used for information such as
OK	Caution	Cancel
Accept	Wait	Hazard
Proceed		Stop
		Delete

An enormous amount of research has dealt with color preferences. The following lists the colors which are typically used for representing traffic condition on the map.

Figure 3. 13 Typical representation of traffic information using color

The use of colors can increase the efficiency of graphics but can also increase the complexity if too many colors are used. The meaning of colors has to be understood intuitively and in a similar way by all drivers. Color search is three time faster than serial search for targets coded using shapes, according to Treisman (1982) cited in (Lohse 1997). A designer can improve the design by using color coding scheme that maintains adequate color separation.

Full color information panel (FCIP) is one of the examples of color application for dynamic route information (Harms et al. 2005). Colors enable indication of the size of a congestion and the location of the congestion. Despite this, color-coded routes serve as eye catchers which immediately direct the attention to the road (Harms et al. 2005). Choosing the right color combination for directing attention is crucial because a wrong mixer of color might lead to wrong interpretation. Color coded network for in-vehicle map, mobile map and also color coded congestion map in the graphical information panel has been used widely. Figure 3.14 to 3.16 listed some examples related to the use of this color coded map as a performance indicator.

Figure 3. 14 Color coded map display for in vehicle system

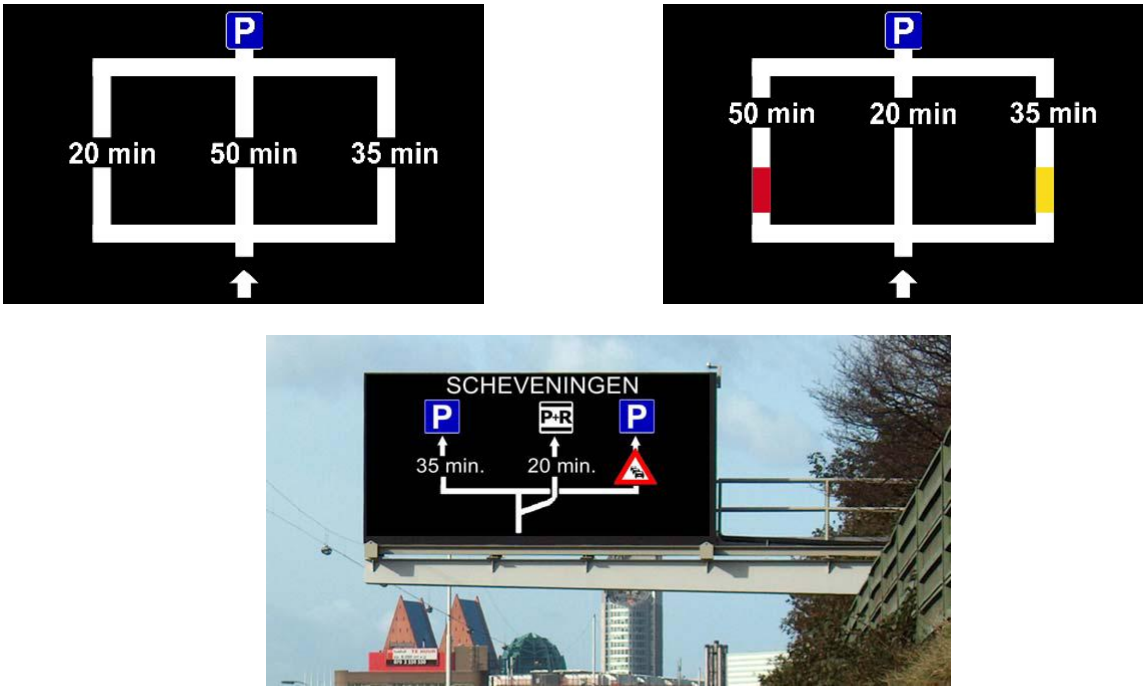


Figure 3. 15 The design of Full Color Information Panel (FCIP) with congestion depicted in red color, extra and information through other color coding (yellow) as in http://extras.hfes-europe.org/

Figure 3. 16 Color coded map display on mobile phone

3.5. Driver behavior towards different traffic information styles

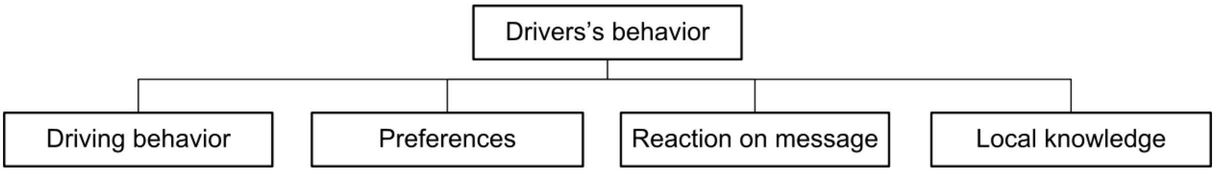


Figure 3. 17 Driver behavior submodel according to Konig et al. (1994)

Numerous researchers analyzed driver preferences towards various information presentation styles. Their focus includes the way information is presented as the content of the information. Others discussed the impact of presentation on driver behavior. One of the early studies was reported in Konig et al. (1994) where the authors considered four sub-models that influence driver behavior as in Figure 3.17. Ng et al. (1998) worked on the same theme, where they agreed information about drives' attitudes, preferences, driving strategies and reactions to traffic information must be obtained together with their cognitive and information processing abilities (see Figure 3.18)

Figure 3. 18 A user centered design strategy for ITS

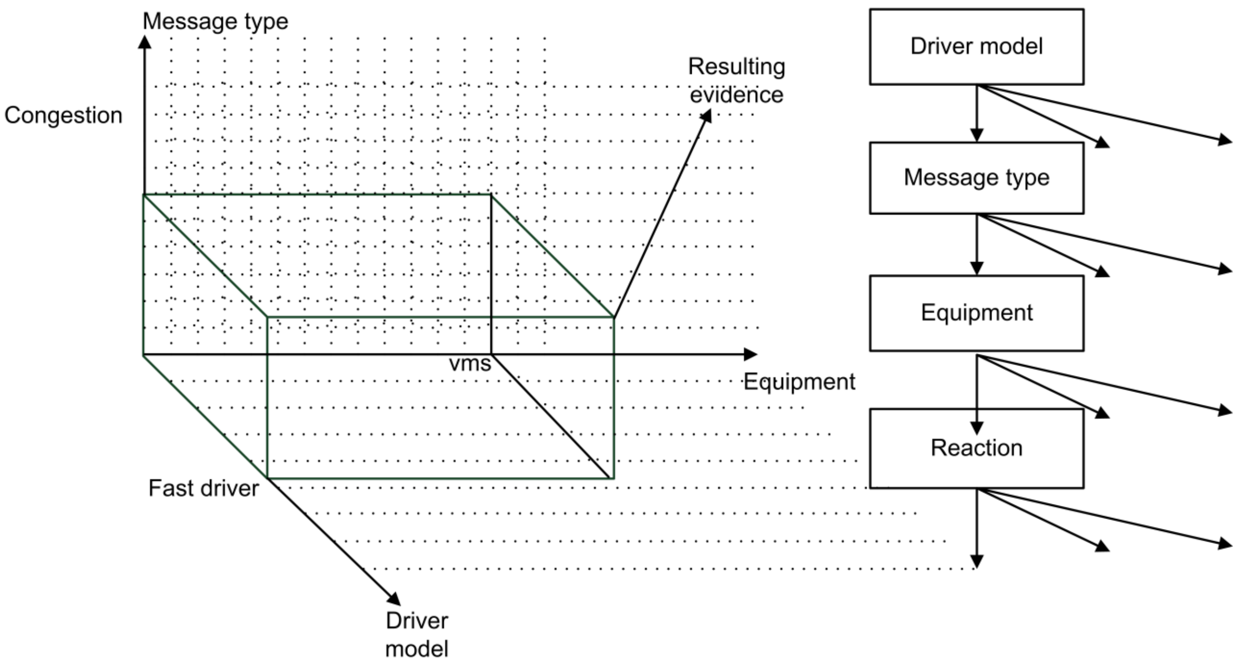


Figure 3. 19 The relationship between message type, dissemination channel and driving model (Konig et al. 1994)

The relationship between message-type, the used transmission- media and the driving model is shown in Figure 3.19. According to which, the probability of accepting a message is only relevant for one receiver of one message. The fact whether a driver takes certain messages into consideration depends on:

- spatial validity: a message has a spatial validity, if the driver reaches the sphere of influence of the event announced by the message while maintaining his actual route planned beforehand.
- temporal validity: the point in time at which the event announced in the message will take place.
- frequency : the frequency of a message/of messages announcing the same event (with different parameters).
- content of the message
- period of validity: the period, during which the content of the message will be valid.
-

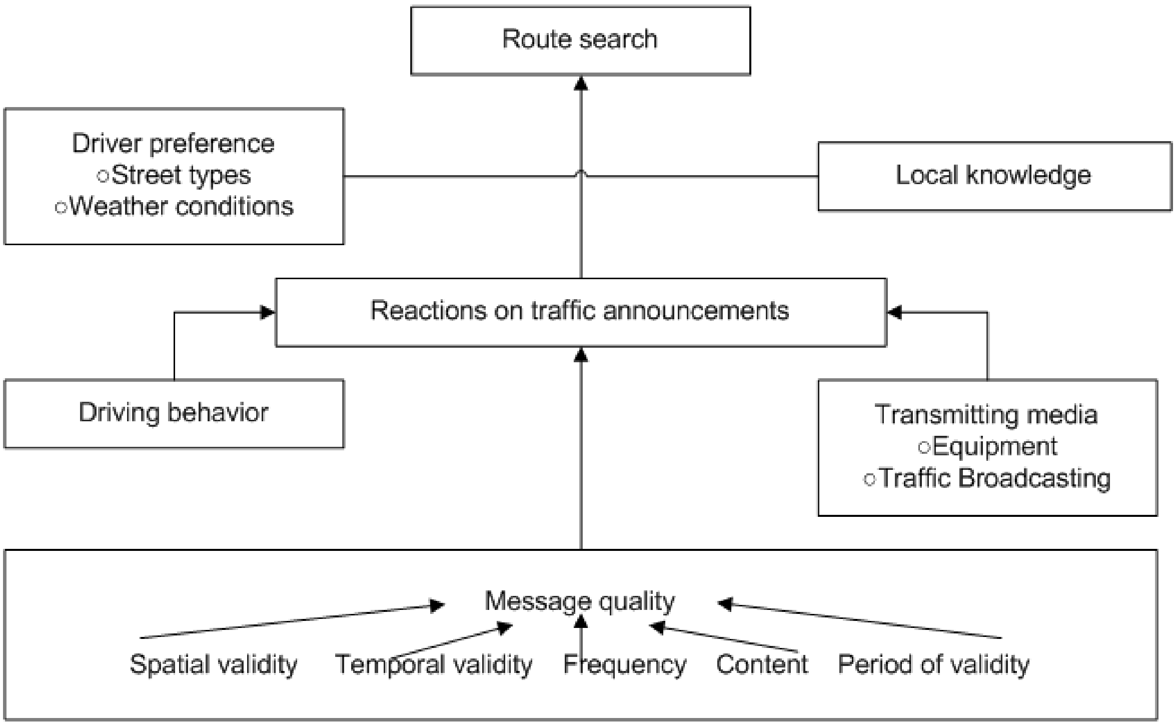


Figure 3. 20 Relationship between local knowledge, driver preferences, reactions on traffic announcements and route search (Konig et al. 1994)

The driver has to check whether the information is relevant to him concerning his route. The driver’s decision to accept or reject the information mainly depends on the respective driver model as shown in Figure 3.20.

Besides the analysis of the influence of presentation style on driver behavior, other studies tried simply to quantify the impact of other human factors to driving behavior. In similarity with the previously mentioned studies, the quantification is made throughout the measurement of several dependent variables used to verify the consequences of the task performance. An example is the decision after receiving specific information.

This section focuses on the impacts of traffic information on drivers. The forthcoming discussion will be based on six different questions:

1. What type of information?
2. Which platforms/channel of the information and the techniques?
3. Which preferences of the driver towards different styles of traffic information?
4. What type of behavior?
5. What kind of traffic state?
6. Which critical factors that might affect the driver?

The input information can be classified into information for the driver, and information for the traffic management control. Information to be sent to the driver must be in a good format to be easily seen, read, understood, and memorized (Ka-hung and Wing-gun 2000). Seven characteristics of traffic information was defined by Lappin (2000) which are accuracy, timeliness, cost (capital and operating), degree of decision guidance and personalization, convenience (ease of access and speed) and safety (of operation). Reliable travel time, speed information and travel delay are useful to the driver. There are several platforms where the user can browse/get the information (before or during the trip). For example using internet, via VMS (variable message sign) or using GPS navigator. Using internet to distribute the traffic information has also been utilized widely. Effective presentation techniques help to change information that needs more conscious thought and are easier to understand intuitively.

One of the main considerations for developing and marketing traffic information systems is to understand traveler behavior. How people make travel choices (including destination, mode, departure time, and route) is a reaction of their knowledge of the traveling environment and their personal preferences and needs toward travel (Adler and Blue 1998). Besides, the authors also suggested some general issues in the context of understanding driver behavior and the effect of traveler information systems:

1. Determining traveler preferences for ATIS including type of information, type of display and presentation media.
2. Understanding and modeling route choice/switching behavior focused on the factors and needs that influence the decision processes.
3. Representing and modeling cognitive processes, including spatial cognition and cognitive maps, that affect routing behavior and the need for information.
4. Assessing and evaluating the effects of ATIS on network performance using traffic simulation.
5. Conceptualizing dynamic models for analyzing the interaction between traveler behavior and ATIS.

According to the list, drivers want to be able to make their own decisions regarding display styles of the information. This is partly supported in other studies for driver's preferences such as Lai and Wong (1998) who found that driver preference could be affected by presenting identical traffic information in a different format.

The basic contention of providing useful platform and information presentation style is consistent with Dicke-Ogenia et al. (2008) where the authors argued that information provisions may help to use the travel network more efficiently as they help to change behavior. Two types of influences, cognitive ergonomic and social psychological principles, were extensively discussed, as summarized in Figure 3.21. Conspicuity, legibility, comprehensibility, and credibility are among the cognitive ergonomic guidelines whereby habit, the elaboration likelihood model, attitudes and theory of planned behavior are the social psychological principles that may also have an effect during the information processing. For example, legibility determines how easily a sign can be read is the influence of the third step of information processing: comprehension of the information. A prerequisite for comprehensibility of a message is that the traveler is able to process the information. The use of color to indicate position and severity of congestion (for example a red block over a road) enhances legibility. The color immediately makes it clear that there is a deviation from a normal situation.

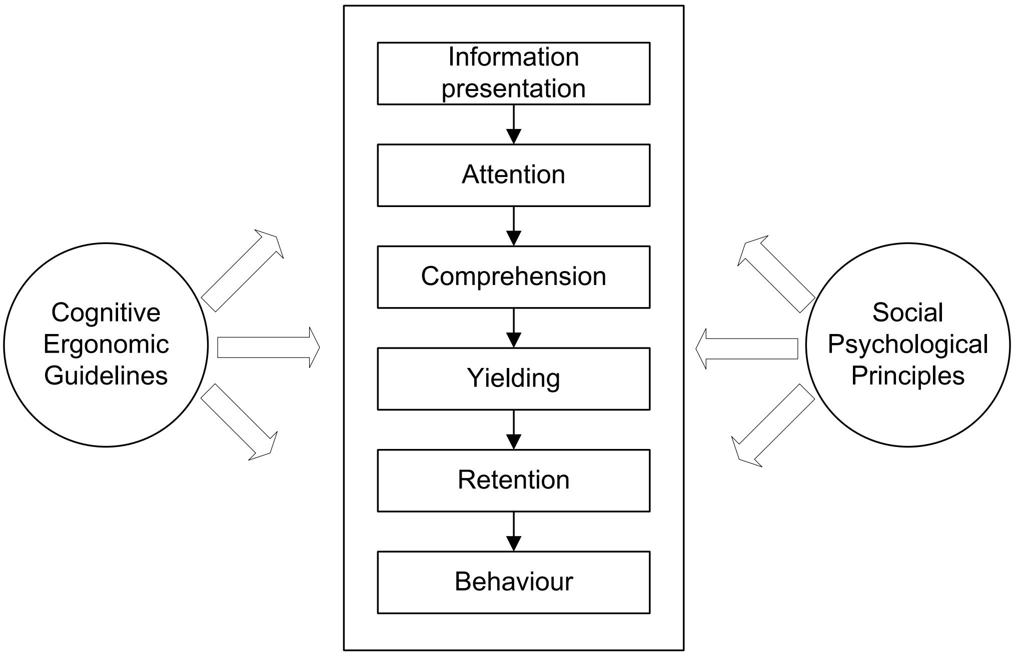


Figure 3. 21 An overview of the influence of cognitive ergonomic guidelines and social psychological principles on the information-processing steps as summarized by Dicke-Ogenia et al. (2008)

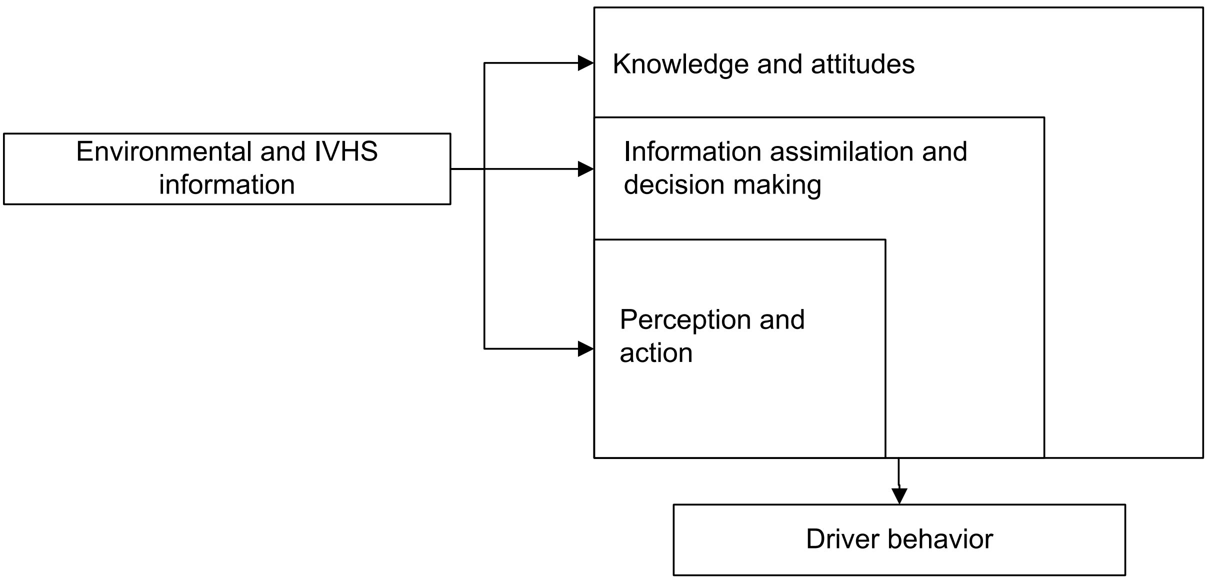


Figure 3. 22 Three areas of cognitive characteristics and their relationship to driving behavior as in Barfield and Dingus (1998)

Figure 3.22 shows information from the environment and ITS component may be medicated by characteristics of the perceptual system, decisions making limit and driver knowledge and attitudes. These cognitive characteristics imply constraints on what information drivers require and how that information can be best displayed. Knowledge and attitudes reflect perceptual and motor limitations which affect information access and driver response capabilities. Driver attitudes are believed to have a powerful connection with drivers' compliance with route guidance and warning notifications (Barfield and Dingus 1998). On the other hand, information assimilation and decision making influence the drivers' ability to interpret and understand the meaning of displays and decisions they imply. Specifically, how drivers integrate information from the environment and ITS components to find alternative routes that might shift them from congestion are determined. Table 3.4 listed driver characteristics and design constraints associated with information assimilation and decision making.

Table 3. 4 Cognitive characteristics of information assimilation and decision making and related information requirements (Barfield and Dingus 1998)

Cognitive characteristics	Design solutions
Limited divided attention	Collocate similar information
Limited focused attention	Recognize the potential to distract drivers from their primary task with excessive information
Age-related decrements of divided attention	Provide redundant information sources
Mental overload	Minimize noncritical information in times of high workload
Faulty task prioritization	Include priority cues in messages to drivers
Time misestimation	Display estimated time for routine and alternative routes to show travel time savings associated with deviation
Limited literacy (written)	Use icons, make system use possible without reading a manual
Limited literacy (math)	Minimize need to calculate values
Language differences	Use icons
Lack of computer familiarity	Do not rely on computer metaphors
Icon interpretation	Identify with text coupled with standardization

The terminology of driver reaction or driver behavior is related to what the driver actually does. This term is different from driver performance when we actually look at what the driver can do. Driver behavior is what the driver chooses to do with these attributes. Several researchers investigated driver behavior when receiving information via VMS mainly in relation to speed reduction and choice of route. (Wardman et al. 1997) found three classes of VMS impacts which are the content of the message, local circumstances and drivers' characteristics. In this study, three possible behaviors will be analyzed which are mode of change from private vehicle to public vehicle or vice versa as well as route choice, change of transportation mode and stay on route/do nothing.

i. Change of mode – from car to public transport or vice versa

With the influence of traffic information, the driver will possibly change their mode of transport, for example, changing transportation mode from private vehicle to public transport or vice versa.

ii. Change of route (route choice)

The driver response on route choice has been surveyed widely. Dia and Panwai (2007) discussed the driver's compliance and route choice behavior towards the travel information. Analysis of the impacts of socioeconomics, context and information variables on individual behavior and propensity to change route and adjust travel patterns were done through agent-based neural networks (Neugents). Their results indicate that three different types of traffic information formats namely prescriptive, predictive and quantitative real-time delay information provided for both the usual and best alternate routes are most effective in influencing commuters to change their routes. Peeta and Ramos (2006) also investigated the effect of different types of VMS message on driver behavior towards route choice using a binary logit model and the maximum likelihood estimation procedure was used to estimate the parameters of the model. Other researches (Bierlaire et al. 2006; Ben-Elia et al. 2008; Chatterjee et al. 2002; Erke et al. 2007; Jou et al. 2005) reported the analysis of driver response towards route choice while Erke et al. (2007) compared the route choice, speed and braking behavior towards the displayed of VMS service.

iii. Stay on route / do nothing

When a driver is on the road, some factors that might influence the choice of route includes journey time, distance, monetary cost, congestion and queues, type of maneuver required, type of road, scenary, signposting, roads works, reliability of travel time and habit (Ortúzar and Willumsen 2001). Route choice factors were in grouped by Jan et al. (2000) into 4 different groups as in Table 3.5. Traveler, route, trip and other circumstances are factors that affect the driver in making decision.

Table 3. 5 Route choice factors (Jan et al. 2000)

Traveler	Age, sex, life cycle, income level, education, household structure, race, profession, length of residence, number of drivers in family, number of cars in family, etc.	
	Road	Travel time, travel cost, speed limits, waiting time. Type of road, width, length, number of lanes, angularity, intersections, bridges, slopes, etc.
Route	Traffic	Traffic density, congestion, number of turns, stop signs and traffic lights, travel speed, parking, probability of accident, reliability and variability in travel time, etc.
	Environment	Aesthetics, land use along route, scenery, easy pick-up/drop-off, etc.
Trip	Trip purpose, time budget, time of the trip, mode use, number of travelers	
Circumstances	Weather conditions, day/night, accident en-route, route and traffic information, etc.	

A study conducted by Allen et al. (1991) examined the effect of in-vehicle navigation system display formats on driver route diversion. Laboratory simulation was used with a total of 277 drivers as participants. Their results showed that drivers diverted much sooner when they knew the delay was long (30 minutes). In addition, the helpfulness of various types of information was reported in Hoekstra et al. (1992). Table 3.6 shows the information rank that varies among five forms of information for their route planning. The preference data is based upon impressions from seeing pictures of the screens in a laboratory and not from actually using the information while driving. The authors measured the distraction of the traffic information display by how often and how long drivers looked at the information. Times estimates were considered the most helpful information for the drivers.

Table 3. 6 Ranking in terms of helpfulness of various types of information as in Hoekstra et al. (1992)

Rank (1 = most helpful)	Information style
1.79	Times estimates
2.32	Text messages
2.86	Photos of actual conditions
3.17	Color coded maps
4.51	Bar graphs

Hoekstra et al. (1992) has also reported the rank order of presentation style that is preferred by the driver (from best to worst). Subjects were asked to rank the four systems from best (1) to worst (4), in order of preference. Their results is listed in Table 3.7 where text was ranked the highest followed by graphic, moving video and still video.

Table 3. 7 Mean rank of each information presentation style as in (Hoekstra et al. 1992)

System	Number of ranking				Mean rank
	1	**2**	**3**	**4**	
Text	9	3	0	0	1.25
Graphic	2	7	1	2	2.25
Moving video	1	1	8	2	2.92
Still video	0	1	3	8	3.58

Lai and Wong (1998) analyzed the influence of traffic information presentation format on driver behavior. Their approach for measuring the relationship between driver's perceived traffic information and the format for presenting the information was based on Discrete Choice Analysis from Stated Preference (SP) survey data. Respondents were asked to state their preference on the routes under different hypothetical circumstances as if identical traffic information is presented to drivers in different formats on VMS. The traffic information formats in their context indicate the traffic conditions which are travel time in 'numeric form', level of congestion in 'descriptive form' and in 'switch- on light form' as listed in Table 3.8.

Table 3. 8 The examples of VMS formats according to Lai and Wong (1998)

The Numeric form	Travel time: "20 minutes or less", "21 to 30 minutes", "31 to 40 minutes" and "more than 40 minutes"
The Descriptive form:	Level of traffic congestion: "Smooth", "Medium", "Heavy" and "Congest"
The Switch-on-light form:	Level of traffic congestion: "Nil", "One Light on", "Two Lights on" and "Three Lights on"

Brookhuis and Dicke (2009) investigated the effects of providing travel information to drivers about traffic jam ahead and a potential detour or short cut. The travel information was presented by means of three nomadic systems which are visual mode (using PDA and SMS via mobile phone) as well as auditory mode (simulator mock-up vehicles audio system. They hypothesized that visual systems compete more strong attention with driving task than the auditory system. However, their results showed that with regard to usability, the SMS message was evaluated as less effective than the other two systems, while with respect to cognitive processing, SMS caused more subjective (i.e. experienced) workload than the other two systems. Other studies such as those reported in Muizelaar and Arem (2008) addressed similar issue but with focus on driver preferences for the content of the traffic information. Dutch drivers were asked for their preferences for contents of traffic information for different, non recurrent situations. The top three of preferred content for traffic information is (a) advice for the fastest route towards the destination, (b) location, length, cause and expected duration of traffic jams on the complete network and (c) expected time of arrival with a margin of 5% for an advised route. Choice of traffic information contents also depends on certain personal characteristics. The most important characteristics influencing the preference for traffic information are: usage of traffic information during travel, driver type and age. These findings imply that drivers have different needs for information in different situations. Work by Benson (1996) provide good examples and insight into this topic.

In Benson (1996), methods of displaying information were clarified and the reactions to possible presentations of information on VMSs were as follows:

- There was little enthusiasm (only 33 percent) for using VMSs to display television pictures of road conditions.
- Opinion was evenly balanced for and against displaying maps that depict traffic conditions.
- As a warning of lane closures, motorists preferred a two-tone margin using words instead of graphics (for example, “right two lanes/closed ahead” instead of “lanes ahead closed/ X X”).
- Motorists preferred by a two-to-one margin referring to an upcoming exit as “this exit” rather than “next exit.”
- Motorists preferred by a two-to-one margin identifying an upcoming exit by the exit number rather than the street name of the exit.
- Motorists overwhelmingly (90 percent) supported the idea of placing VMSs on streets feeding into freeways, so that drivers could be alerted to freeway traffic conditions before entering the freeway.

Uchida et al. (1994) had two driver responses to en-route information consideration which are:

- tactical reaction: the relationship between the displayed message and the driver's immediate route choice reaction
- strategic choice: gradual change of route choice tendencies that results from the change of driver attitudes such as reliance, evaluation and way of referring to information (examining the influence of travel time information both on short-time reaction and long-time tendencies).

Gan et al. (2006) also draw our attention to ATIS (Advanced Traveler Information System) with their novel type of ATIS which was designed for network control of expressways. It consists of three new kinds of VMSs which are network-level guidance signs, road section signs, and entrance condition signs. Network-level guidance signs and road section signs provide traffic information in a graphical form, and entrance condition signs provide information about on-ramp conditions in a textual style. The authors point out that since the drivers should be informed about a traffic situation as well as possible, other ways of presenting information should be explored and an ATIS should be designed from a network perspective. A tacit assumption of the basic philosophy regarding the layout of VMSs is as follow:

- The layout should be concise, easy to understand, and creditable and should conform to human ergonomics.

- Road map deformations that greatly distort the driver's sense of distance should be avoided.
- The displayed network should take into account the origin– destination (O-D) characteristics of the VMS location and cover as wide a region as possible.
- Commonality among different items

The most interesting findings related to the effect of information towards driver behavior is that the graphical VMSs had a positive role on assisting drivers in making more informed decisions about congestion avoidance, route selection, and en route diversion, especially under heavy congestion or incident conditions.

In previous studies by Wang and Cao (2005) had some ways towards the effect of display format on VMSs. Their studies considered display format, number of message lines, driving lane, and subjects' age and gender towards the assessment of a portable variable message sign. They found that all main factors significantly affected the response time but not their interactions. With regard to display format, a discretely displayed message took less response time than a sequentially displayed message. For number of message lines, fewer message lines were responded to faster in both discretely and sequentially displayed messages. When driving in the outer lane, subjects took less time to respond to a roadside portable VMS than when they were driving in the middle lane. Their findings on a socioeconomic variable revealed that older drivers exhibit slower response and less accuracy than younger drivers while female drivers exhibit slower response but higher accuracy than male drivers.

As demonstrated in the work by Zhang and Levinson (2008), drivers receive traffic information in several ways. The value of certainty is the most important one as it affects other personal, social, safety, or psychological factors. The benefit of reducing the driver uncertainty when information is provided at the beginning of the trip is the main variable measured in their research. User preferences for routes were assessed as a function of the presence and accuracy of information while controlling for other trip and route attributes. Figure 3.23 showed how a traveler makes a route choice decision given actual attributes of one or more routes.

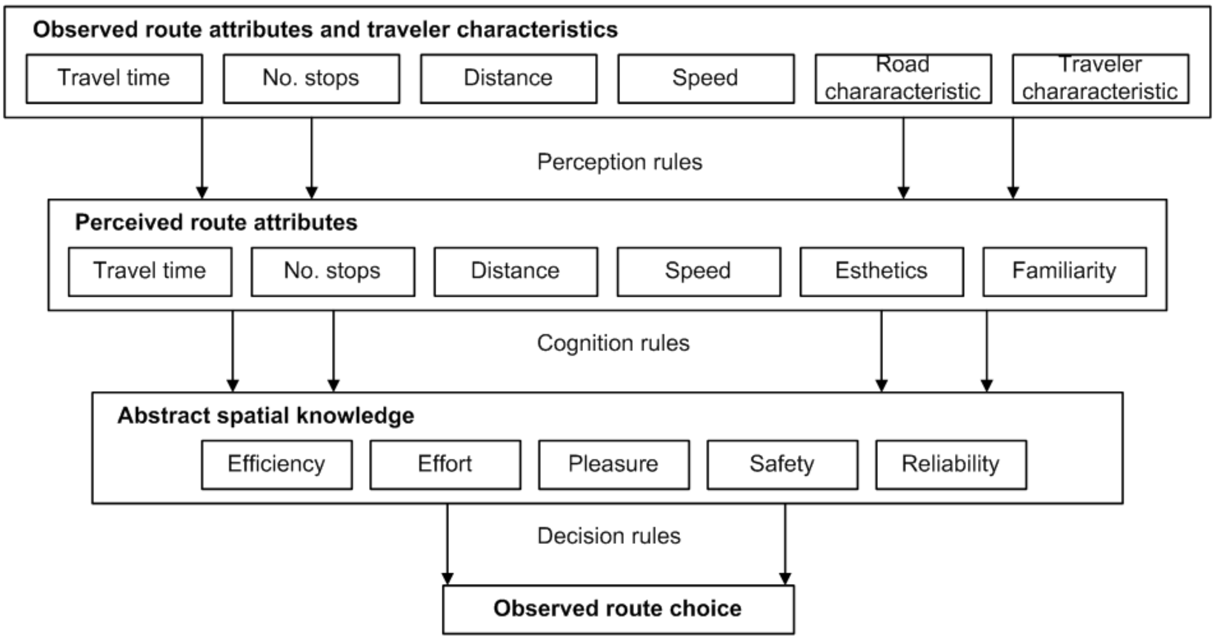


Figure 3. 23 Route perception and cognition as in Zhang and Levinson (2008)

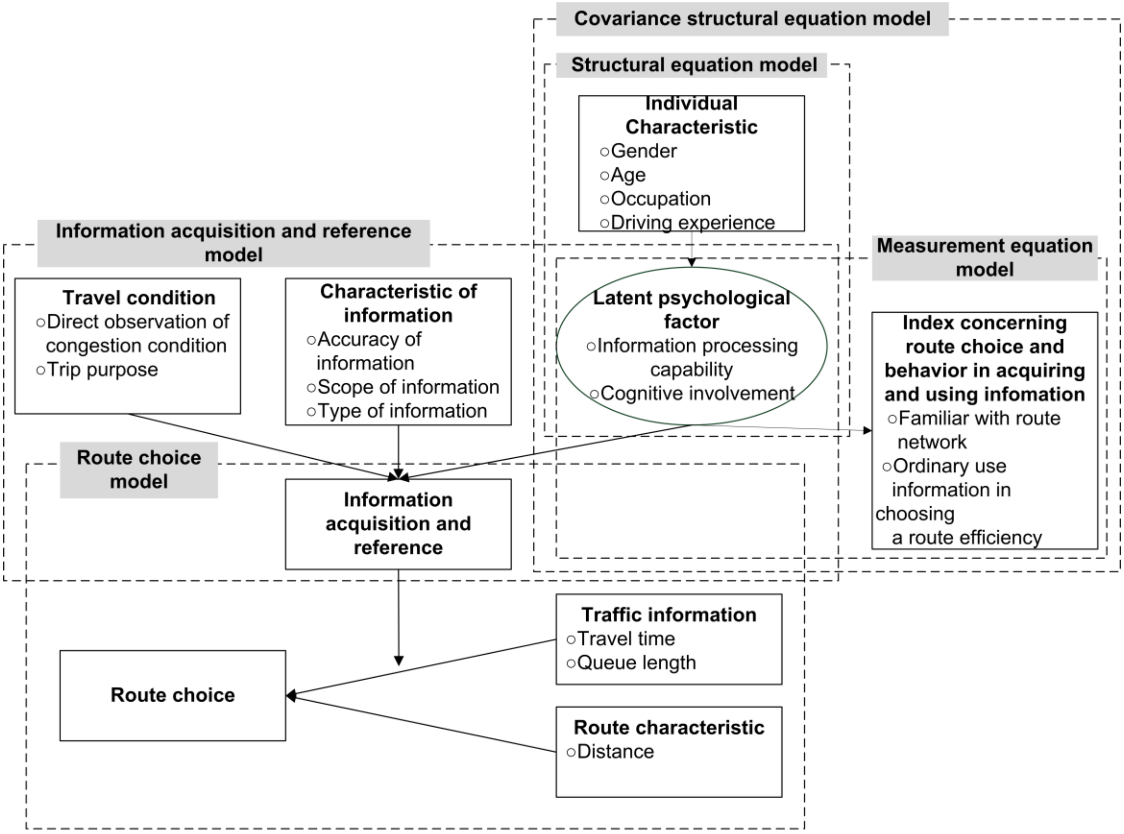


Figure 3. 24 Driver's route choice model under multiple information sources

Hato et al. (1999) developed a route choice model as shown in Figure 3.24 which considers the information acquisition and reference process for the purpose of explicitly expressing drivers' route choice behavior in an environment with multiple sources of traffic information. The model contains trip variables, including route selection characteristics, travel purpose and actually observable traffic conditions en-route such as the degree of congestion, variables pertaining to the information such as its accuracy and extent to which it is displayed, and also latent psychological factors based on the personal attributes and experience of individual drivers. It is assumed that drivers are influenced by these variables and factors in the course of deciding whether to acquire and refer to traffic information in choosing their route. Drivers' latent psychological factors are extracted using a covariance structural equation. Their conclusions include driver behavior in acquiring information from graphical map signs was influenced less by the individual's information processing capability than in the case of the other types of information signs considered. This finding indicates the importance of presenting information in an easily understood format using simple maps.

Peeta et al. (2000) investigated the effect of different message contents on driver response under VMS. Their assumed that message content is a significant factor for driver response and this issue was addressed through an on-site stated preference user survey. Analysis using logit models was developed for drivers' diversion decisions. Their analysis revealed that the content in terms of the level of detail of relevant information significantly affects drivers' willingness to divert. Other significant factors include socioeconomic characteristics, network spatial knowledge, and confidence in the displayed information. Gender and age are socioeconomic characteristics that significantly influence the diversion behavior of an individual. Their results of gender has a positive sign which implying that males are more likely to divert than females under similar conditions. With regard to age variables, it was found that younger drivers are more likely to divert compared to older drivers when all other conditions are the same. Their argument was because females and older drivers are, on average, more risk averse than males and younger drivers.

In addition, Peeta et al. (2000) also addressed some discussions towards the content of VMS. In their study, the message content does not imply details such as number of words or lines, size of words or graphics issues, yet, refers to the amount of information provided on the incident situation. Their findings indicated that as information content increases, driver propensity to divert also increases, provided the information type is considered valuable. Expected delay and best detour strategy are considered valuable information in terms of influencing drivers' route diversion decisions. Location of accident and occurrence of accident have added value only in conjunction with information on expected delay or best detour strategy.

Choocharukul (2008) discussed a better understanding of the interrelationships between the likelihood of route diversion, attitudinal variables, and several exogenous factors such as motorists' socioeconomic status and travel habits (see Figure 3.25). In his study, a structural equation model is developed based on empirical data on road users in Bangkok, Thailand. Derived from factor analysis, three attitudinal variables, namely, awareness of the VMS, VMS comprehension, and perceived VMS usefulness, are extracted and incorporated into the structural equation modeling framework. The modeling results suggest a direct relationship between stated route diversion and two of the attitudinal variables, that is, VMS comprehension and perceived usefulness of the VMS; the awareness of VMS is not found to be a direct determinant of the decision to divert a route. Exogenous variables that appear to be of statistical significance include education, gender, age, daily mileage, and trip purpose. Unlike those in past studies, none of the socioeconomic variables in this study appears to directly influence plans to divert a route. The model estimation results are discussed and practical implications are provided.

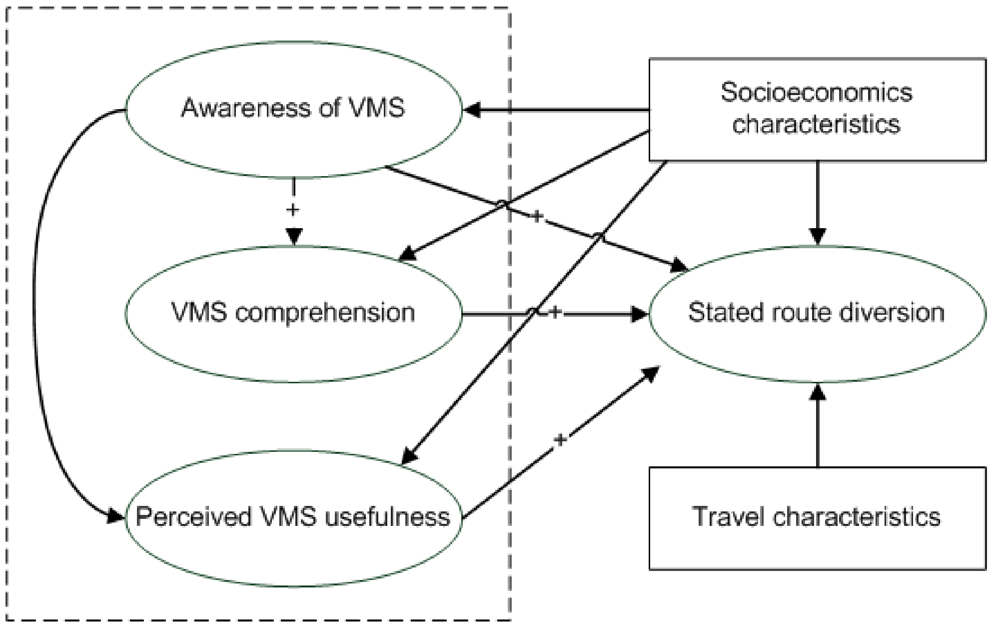


Figure 3. 25 Driver's route choice model under multiple information sources as in Choocharukul (2008)

In addition, based on results reported in Wang et al. (2007), goodness-of-fit tests indicated that most subjects preferred graphic-aided DMS to text-only DMS messages (94% to 6%, p <

0.001.) This result was consistent across all demographic categories of gender, age, and native language. The effects of adding graphics to regular text DMS messages were assessed by a study of human factors through questionnaire survey and lab simulation experiment. Their study also found that graphic-aided DMS messages were preferred by most drivers and were responded faster than their text-only counterparts. The majority of surveyed drivers preferred amber-colored messages; and red-colored messages resulted in the slowest response time. Other interesting results are that graphic-aided DMS messages did noticeably enhance the message response time for non-native English speaking drivers. These two observations point out the value of adding graphics to regular text DMS messages.

An extensive review of previous studies has helped to find out the idea of presentation styles used in traffic world, drivers and their mutual influences, impacts of presentation styles on decision of road users and impacts of user behavior on the selection of presentation styles. Depending on type of information, situation and recipient, traffic information can be presented to drivers in a variety of ways. For example, when travelling on your familiar route, the information semblance may appear familiar irrespective of presentation mode, however, travelling in a non familiar route, local information may lead to misunderstanding and errors, and presentation mode might matter. Two problems were raised by Brookhuis and Dicke (2009) concerning the information presentation. One was the best feasible travel information system when considering usability, safety, perception, comprehension and memory, and task demands and the other was dealing with how older driver and driver with no familiarity with the route appreciates travel information.

Designing a relevant style to communicate the traffic information is a mind-numbing task. One must ask at first what the proper traffic information is. In Hughes (2004) it is suggested that presentation of the information is not only about how things “look” but it is about how it “operates and functions”. The information displayed on a panel, ought to be practical which means fairly simple to process, readable and understandable. Furthermore, in order to successfully persuade particular actions (route diversion, transportation mode change etc.), it is essential that traffic information presentation style is not a work of the experts alone but engages users’ participation. It should be deliberately introduced where wrongly implemented signs may lose the credibility and discourage users from using the system. Therefore, it is essential to conduct a study to figure out what is the impact of traffic information to the drivers.

Chapter 4

Technical fundamentals for traffic data collection and presentation

4.1. Technical Background

The following sections describe the technical framework and method used in this study. This includes the general experiment procedures, equipment used, designed traffic environment, design of experiments, and analysis methods. The study tests at first the assumption that the probe vehicle could provide reliable and sufficient amount of data that could represent travel time information. The second part of the study is concerned with the presentation of traffic information in different styles and the associated driver behavior. The general methodology ranges from data collection, data processing, data application and driver behavior as illustrated in Figure 4.1.

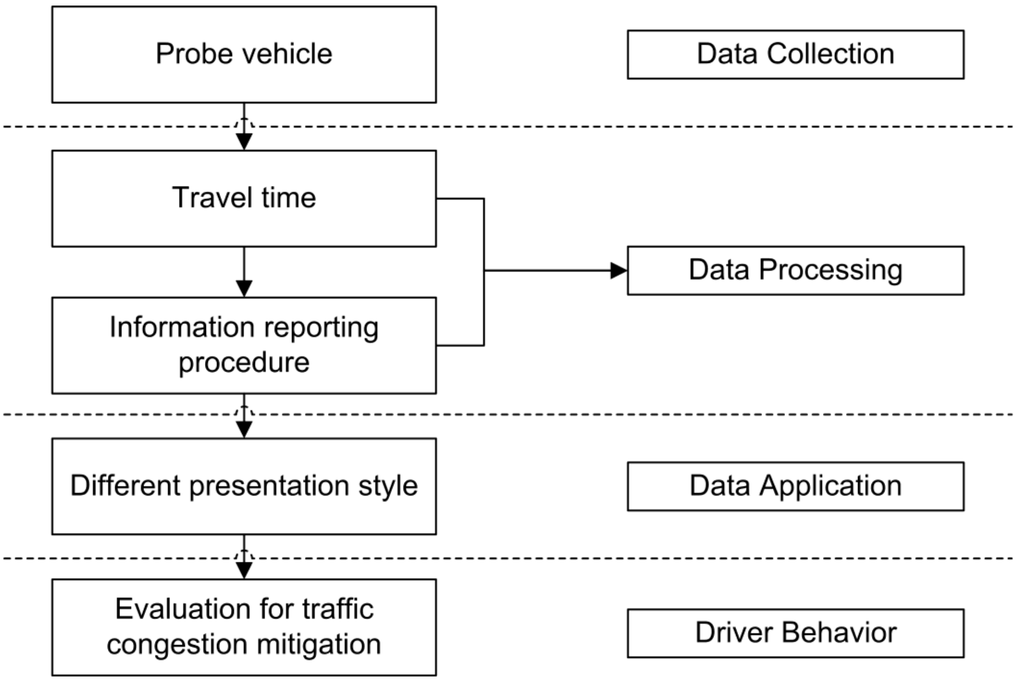


Figure 4. 1 The general methodology employed in this study

The assumption on probe vehicle is tested in a simulated traffic environment. This study focuses on the travel time data, one of the most familiar indexes of traffic level of service. Theoretically, a variety of traffic environments must be considered where the travel times of vehicles represent actual travel situations. However, this study does not attempt to replicate the real world, rather to study travel time generated by probe vehicles in simulated driving environments which help the understanding of the closeness of the travel time from probe vehicles to the “real” one. First, the traffic environment had to be created as a basis for travel time measurement. This study selected simulation as a test bed for generating various traffic scenarios. In principle, a traffic environment is the determinant of three main components: network configuration, traffic flow volume, and control condition. To vary the traffic situation, one or more components must be altered. In this study, the alteration of traffic flow volume is planned, while the network configuration is fixed. The control condition will be altered according to network and flow condition (to the optimal signal control condition). The change of traffic flow condition creates the varying traffic congestion levels, which directly affect the travel time.

Moreover, in the simulated traffic environment the “true” travel time can be approximated and is defined as the actual amount of time that a vehicle spends to traverse on the specified link. Then, the average of “true” travel time is basically the average of travel times of all vehicles passing the link. Data collected by probe vehicles can be considered as the sampling of travel times from all vehicles on streets. It is postulated that the accuracy comes from the random nature of the sampling. The important factor to the accuracy is not only the precision of the measurement on each probe vehicle but also the number of samples to be captured. Statistically, the larger the number of samples, the more accuracy can be gained. The number of samples implies the number of installation of probe vehicle equipment in the entire vehicle fleet, as expressed in percentage of probe vehicles (sometimes know as market penetration). The study expects that the results from travel time estimation from probe vehicles on a hypothetical network are representative and the accuracy of the travel time can be examined under various traffic (congestion) conditions.

The data from probe vehicle can be utilized for several purposes ranging from the traffic demand forecast to the evaluation of traffic level of service (LOS). Some previous representations of outcome indexes of the traffic LOS, such as “map-based traffic congestion” were applied to visualize the accumulated traffic information generated from large amount of source data. However, the reporting procedure of traffic information serves not only the displaying purpose, it should also lead the users to a deeper comprehension of the displayed data. Therefore, it is important to choose specific presentation styles of traffic data that allow drivers to better understand the meaning of the traffic data.

ArcGIS package is adopted to display travel time on all road segments. We take color coded maps (red, yellow and green) to show the variation of travel time along the road segments and to analyze the driver reaction towards different presentation styles of traffic information. A simple underlying hypothesis is basically focused on which presentation style the driver would prefer the most in different levels of congestion and whether the congestion level indicated using different style will impose a large impact on drivers’ decision making. The process is illustrated in a flow chart in Figure 4.2.

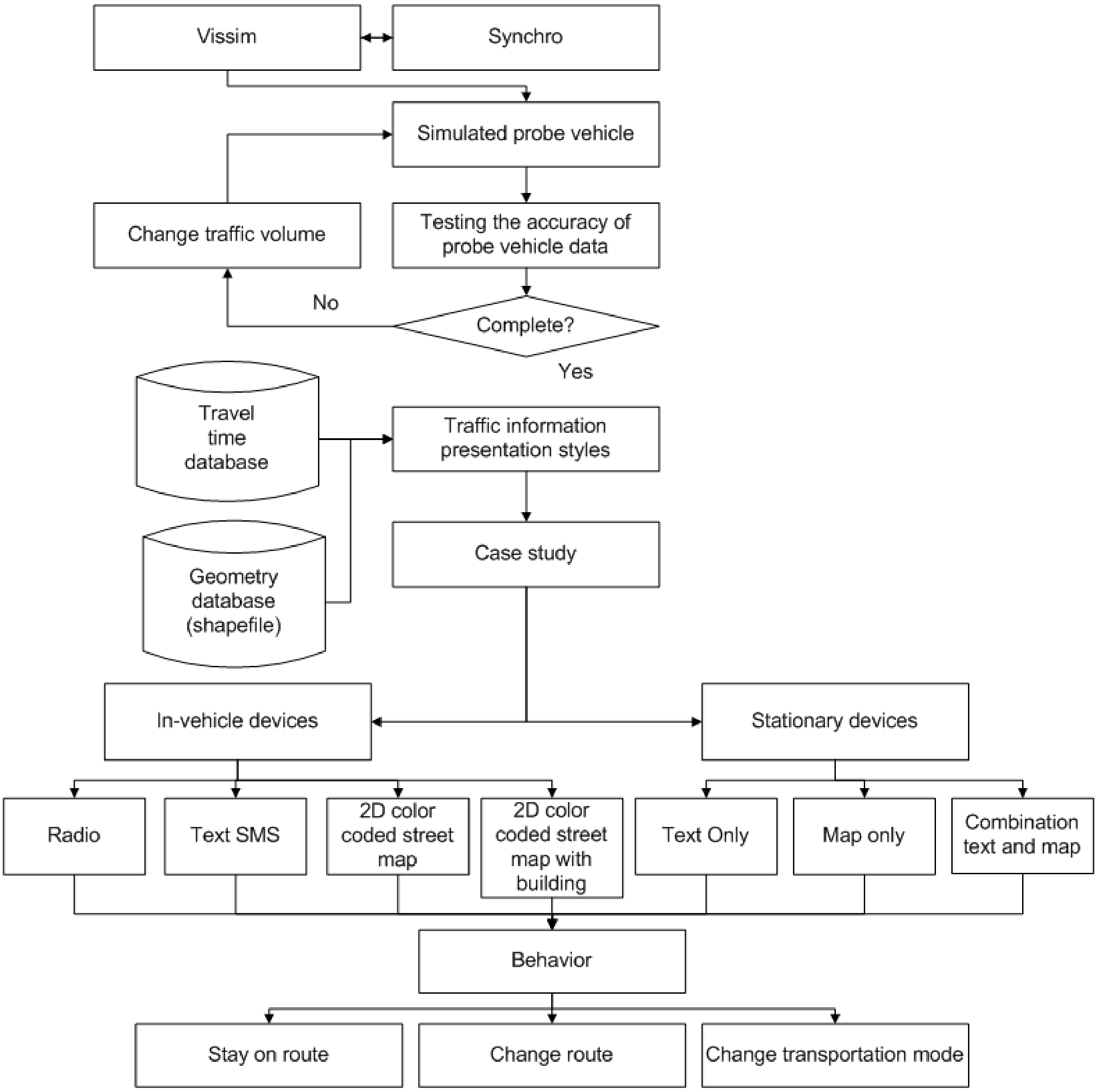


Figure 4. 2 The flow chart of probe vehicle data collection and the test of drivers' reaction on presentation styles

4.2. Data collection and data processing

4.2.1 Simulation software

Simulation techniques provide a new path to generate research data. The main benefit is to get data from various traffic conditions without disturbing the current transport environment. In terms of travel-time study, simulation allows to generate traffic data in both good quality and enough quantity. A microscopic model is more suitable for this study because of its capability of modeling with great detail each individual vehicle in a network. Briefly, during each second of simulation, the program emits vehicles from entry links, moves vehicles in the network using embedded car-following, lane-changing, and gap-acceptance rules, and updates the status of various signals in the network. Although simulation has its own problems related to high level of detail and input data requirements in addition to the need for proper calibration and validation, it offers a viable alternative to field data collection. The major advantage of traffic simulation is that once a model has been developed and validated, it is possible to generate data for a wide range of situations. A well-known microscopic traffic simulation model, VISSIM 5.0 was selected to simulate the traffic flow on the road. It can modulate the data including the percentage of probe vehicles, inflow and outflow volumes and accomplish a reasonable distribution of vehicles by assuming that some percentage of the drivers will divert to alternative routes to avoid congestion. More precisely, VISSIM is used for the following purposes:

1. As a test bed to generate pseudo research data.
2. Illustrate the use of probe vehicle, probe percentage of fleet, movements, tracing as well as a display medium of all vehicles in the test network.
3. Illustrate dynamics of queue's building-up and dissipation.

In Vissim, a variety of traffic environments can be created and travel time of probe vehicles on a hypothetical network can be determined. Probe method is used as another option of getting data in case there is no placed detector to collect the travel time information. The accuracy could be examined under various traffic (congestion) conditions and the estimated travel time will be stored as database for further analysis.

4.2.2 Travel time data collection through a hypothetical network

In order to illustrate the potential of a probe vehicle in providing traffic information, a hypothetical network is required which can be modeled in VISSIM 5.0. As shown in Figure 4.3, the hypothetical network consists of 6 traffic intersections. Each road link has two lanes in each direction. Each lane is 3.5m wide with 80km/h speed limit. Three scenarios corresponding to three different LOS were created as information sources. Table 4.1 shows that by loading extra vehicles in the network, the level of service of every intersection becomes low. For every network with different levels of congestion setting, only one run with the same seed number for each traffic level was set. The simulation was run for 5400 seconds from which 600 seconds were the warming-up time. Synchro 4, Traffic Signal Coordination Software was used to optimize the traffic signal settings for every intersection. The advantage of the signal optimization was to reduce overall intersection delay and to provide the optimal signal setting for the entire network.

The optimum signal setting from Synchro 4 was determined for each scenario. It should be noted that the optimization was done in order to create traffic scenarios with different congestion levels. The recommended signal timing was the result of an optimization strategy. It involves several performance measurements including the length of queue and delay. Actuated traffic controller was specified in the network. Once the level of service for every network was obtained, the optimum setting for the cycle length together with the offset setting were transferred into VISSIM 5.0 for further simulation.

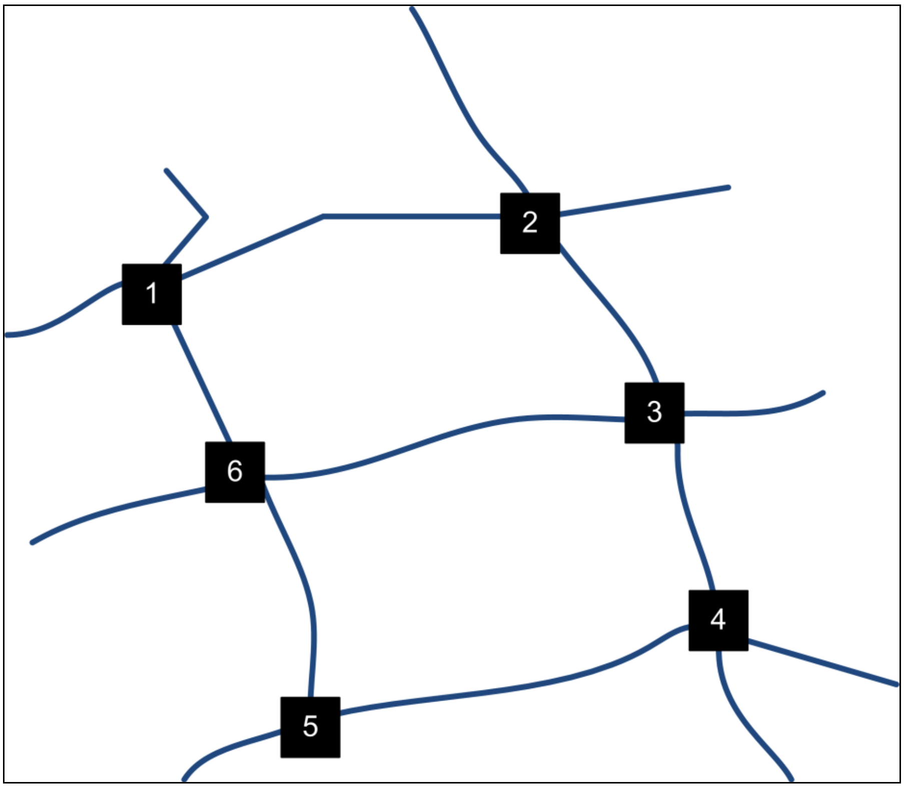


Figure 4. 3 The hypothetical network

Table 4. 1 Three LOS for each intersection

Intersection 1	Intersection 2	Intersection 3	Intersection 4	Intersection 5	Intersection 6	Average LOS
A	A	A	A	A	A	**A**
D	D	C	E	A	C	**D**
F	E	F	F	A	F	**F**

The design of the hypothetical network was determined so that it covers a broad range of traffic volume and represents typical traffic situations which might give the various effects on the probe vehicle travel times. Traffic conditions on roads can be measured in terms of Level of service (LOS), ranging from A (free flowing traffic) to F (highly congested). Our study has the purpose to detect the difference between the link travel time of probe vehicles and the 'true' link travel time. The 'true' average link travel time was measured by summing up the travel time from all vehicles passing the link divided by the number of vehicles passing the link. On the other hand, since all vehicles in the network came with a unique ID (identity number), the probe vehicle travel time was measured by matching the ID of the vehicle in the link with the ID of the vehicle specified as probes, and the average travel time of probe vehicles was calculated.

As the first step, we input "travel time" stations in VISSIM 5.0 to perform exactly the same task of producing travel time. By placing such stations in VISSIM 5.0, the whole road network has been divided into many short segments. We collected simulated travel time of the vehicles in 1 second interval. The probe vehicle was not specified at the beginning of the simulation, but the iteration of producing and assuming some vehicles to be probe was set after the simulation stopped and data were generated. For every dataset (different levels of congestion), ‘bootstrapping’ was made for 500 times. This meant that a set of vehicle ID was selected for 500 times randomly and the travel time of each ID was identified in order to get the variation of travel time. The ‘bootstrapping’ was conducted for 10%, 20%, 30% and 40% sample of probe vehicle in every network. Application of bootstrapping to estimate probe vehicle travel time might allow us to use smaller samples in validation studies, thereby reducing the costs.

In this study, for every network with traffic volume setting, the travel time for every vehicle together with vehicle unique ID was gathered. Some of the vehicles were specified to be probe vehicle. However, the specification was not done at the beginning of the simulation, but the iteration of producing and assuming some vehicles to be probe was set after the simulation stop and data was generated. The power of bootstrapping comes from its first step, resampling with replacement. As the resampling goes on with replacement, indirectly creates many new data sets from one sampled set of data, simulating the variations in data that would be seen if many more samples were taken. In order to resample, elements are randomly chosen from an original set and added to a new set of the same size as the original one. However, when a sample is chosen it is not removed from the original set. It is particularly useful when no simple expression is available to compute the summary statistics for a measure or only a limited sample size is available. The process essentially involves taking repeated subsamples from a larger sample (with or without replacement) and calculating the statistic of importance based on this subsample. The distribution of these subsample statistics is then used to infer information about the population as a whole.

Bootstrap technique had some application within the transportation field. Rilett et al. (1999) used the bootstrap technique to estimate the variance of freeway travel time forecasts derived from an artificial neural network where it allowed predictions to be made of future confidence intervals for journey times along a freeway. Besides, there is also study by Brundell-Freij (2000) that focuses on assessing the accuracy in the estimates produced by complex transport models. They used a combination of Monte Carlo simulation and bootstrap techniques to show how different kinds of variation in the input data affect the quality of the final model estimates.

4.2.3 Data analysis

Based on the random probe samples, the analysis is conducted to determine how close the estimation of link travel time and route travel time matches with the ‘true’ data. Again, in VISSIM, warm-up time needs to be classified to account for the discrepancy that occurs when the simulation starts and the system is empty, but in reality there are cars in the system. Hence, by skipping the first fifteen minutes, the link and route travel time estimation process is conducted for the remaining time period. For example in the case of 4000 veh/h in the network, the data generated for the remaining 45 minutes was 3200 vehicles. Therefore, the iteration of probe vehicle sample was done as 10% from 3200 vehicles. For further understanding regarding the bootstrapping iteration done in this study, the full process is illustrated in Figure 4.4.

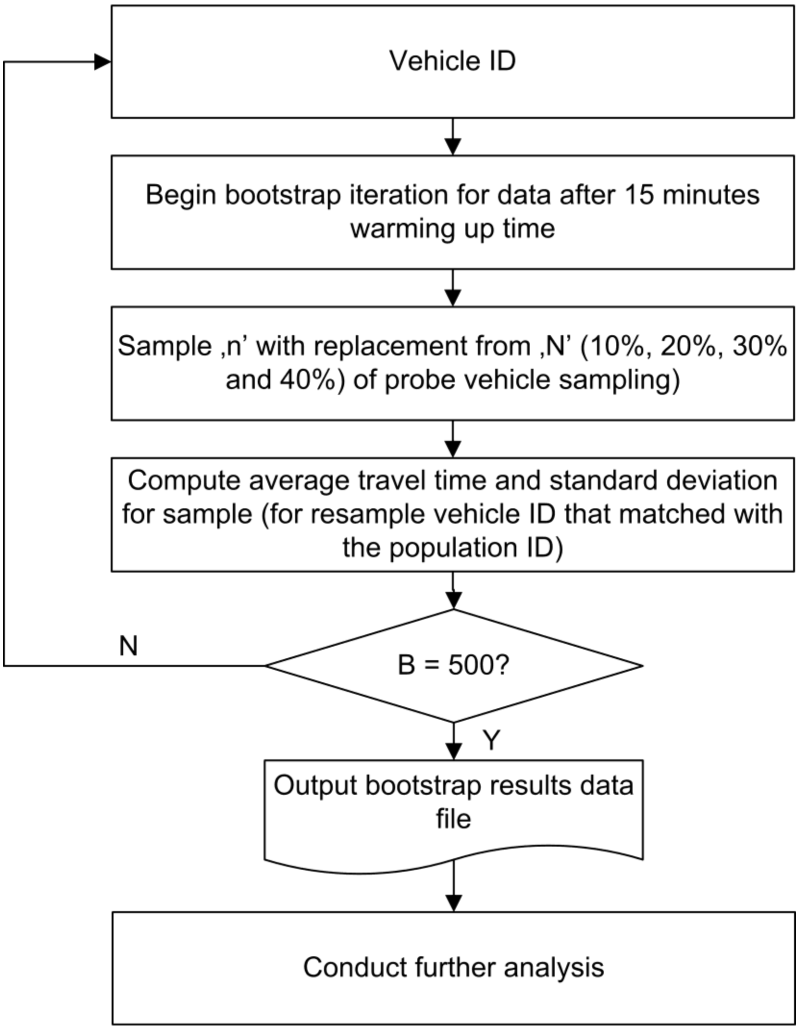


Figure 4. 4 Bootstrap Iteration for probe vehicle re-sampling

Finally, it is important to make sure that information received by the user is fully utilized and successfully received. Taking into account the power of GIS as a visualization tool, we employ in this study ArcGIS to display the results of travel time provided by probe vehicle in a more understandable visual fashion. As described in previous paragraph, the travel time provided by probe vehicle is stored in database. Therefore, as application of the travel time provided by probe, road network using color map for the entire test network was created. The flow diagram is shown in Figure 4.5.

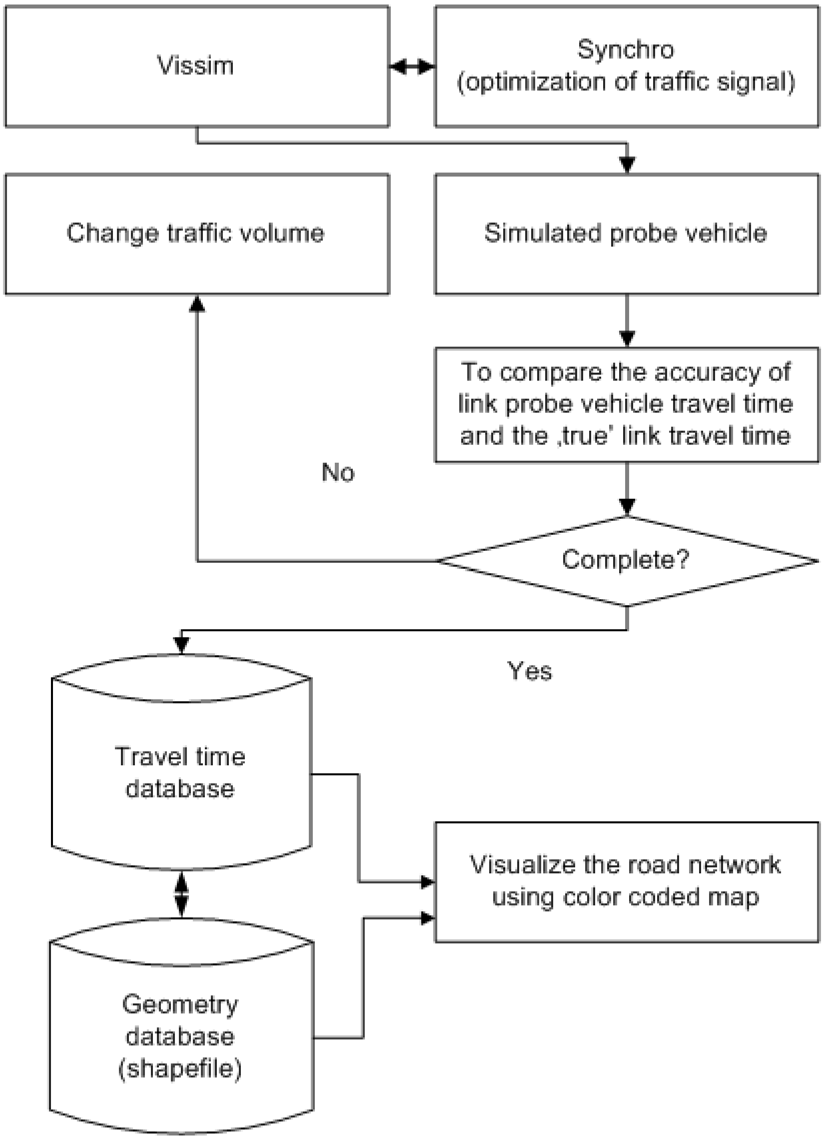


Figure 4. 5 Flow diagram of collection and processing of travel time in simulated environment

4.3. Presentation of traffic information

In this study, results generated from traffic simulation software were combined with ArcGIS. Data visualization is the study of the visual representation of data, defined as information which has been abstracted in some schematic form. When representing traffic information, the presentation style should support the information processing in real time. Too elaborated process is not suitable for short decision time in heavy traffic conditions. Therefore, in order to trigger a desirable change in behavior, the information should allow adequate time for the driver to understand and subsequently make a choice. For example, using red on a road map to indicate location and severity of congestion indicating that other routes may be better to travel, or using green to indicate that a route is not congested and as a result is advised to travel. A case study is designed in this work with the purpose to interpret user preferences towards traffic information style for both in-vehicle and stationary system. In-vehicle information can be received in the vehicle while stationary information is basically provided along the roadside. We made an assumption that any provided information will create change in any value of the system performance and also in driver behavior. Variations in the information display lead to changes in the anticipated effort of each available information and therefore provide incentive for them to use different decision process. Therefore, a preference survey was carried and designed for a variety of traveling scenarios, which then yield understanding on the decision upon presentation style of traffic information and decision made by the driver at different level of congestion.

4.4. Driver behavior

4.4.1 Stated preference survey

Figure 4.6 shows the process of the traffic survey with 5 stages. The aim of the stated preference survey is to measure the preferences of the driver towards different presentation styles of traffic information. Besides, we also want to examine whether the presentation style of traffic information will influence the behavior of the driver. Therefore, it is necessary to collect not only preferences data, but also differing characteristics of each driver such as trip characteristics, socio-economic characteristics and the respondent's response after receiving the information. The hypothetical scenarios should take into account traffic conditions and travel purpose. We assume that the interaction of drivers with different presentation styles of traffic information can lead to an increase on the driver's mental workload, inducing to an impact on the driving behavior. More specifically, it was hypothesized that:

1. Driver preferences towards presentation styles revealed that visual presentation will be ranked the highest among all.
2. Receiving different presentation styles of traffic information will change the drivers' mental workload which may later have an impact on driving behavior.

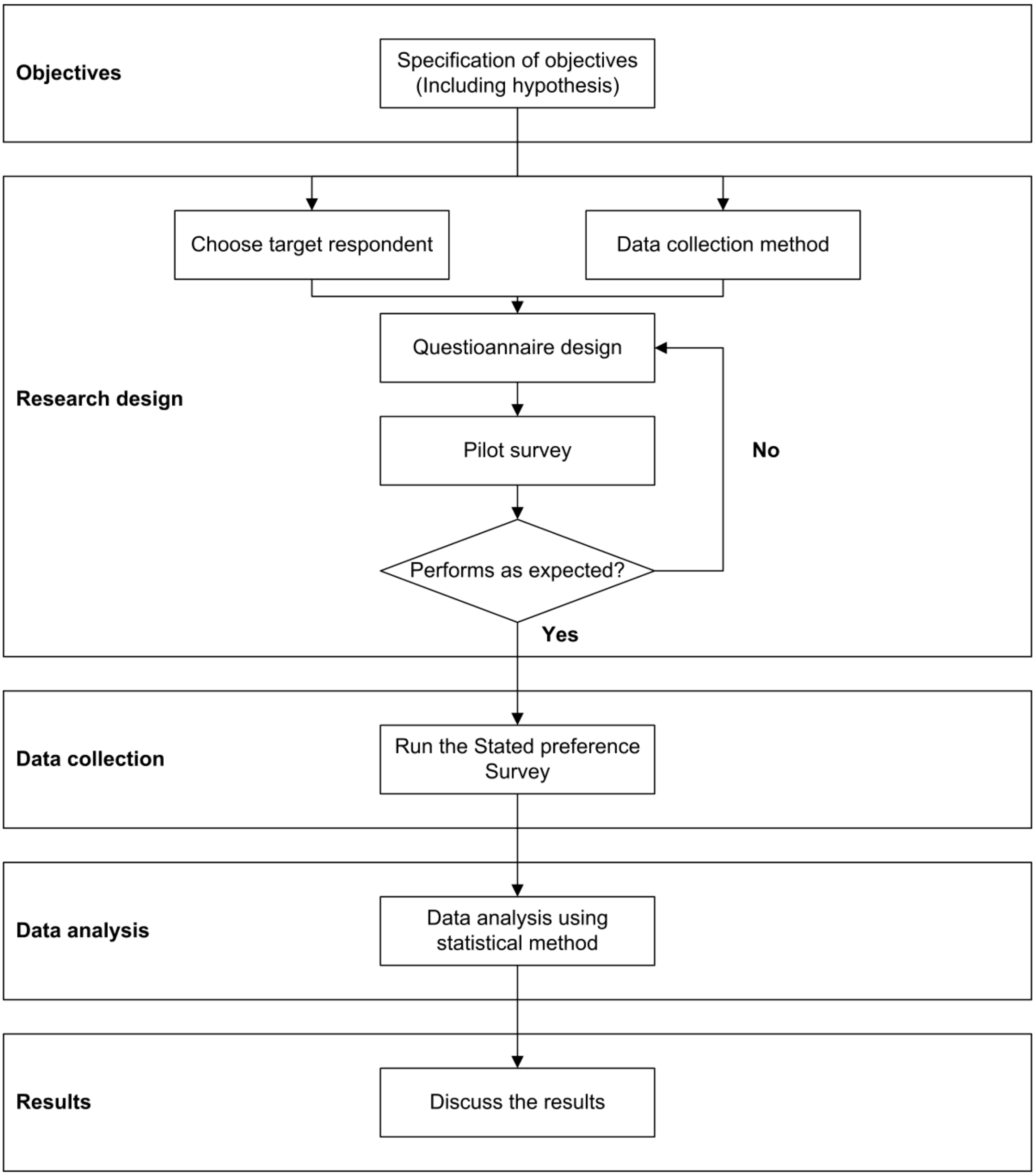


Figure 4. 6 The flow diagram of the stated preference survey

4.4.2 Questionnaire design

Four main things need to be considered for a questionnaire design: the target respondents, the data collection methods, the questions as well as the pilot survey. The target respondents are drivers with variety of socioeconomics background. Basically, there are two types of questionnaires survey: revealed preference survey and stated preference survey. In revealed preference survey, the questionnaires are distributed to indicate how the travelers or drivers behave in real life situation whereas in stated preference survey, the respondents will be asked to choose between different alternatives in hypothetical scenarios. These two approaches of survey have been extensively used in practice. For example, Richards and McDonald (2007) used revealed preference questionnaire in combination with travel diaries to evaluate user response to VMS in an urban network. Their research focused on user acceptance of VMS located in an urban road network of Southampton in UK and investigated the public's perceived effectiveness and usefulness of these signs. Ka-hung and Wing-gun (2000) used stated preferences (SP) to examine driver comprehension of the traffic information that is presented in three formats, namely, the numerical format, the description format, and the switch-on-light format. Their questionnaires with well-designed attributes regarding travel conditions and a total of 475 cases for Hong Kong drivers were examined.

Peeta and Ramos (2006) reported the results of VMS driver response models for the I-80/94 corridor in northwestern Indiana using SP data collected through three different administration methods: an on-site survey, a mail-back survey and an Internet-based survey. On the other hand, Bierlaire et al. (2006) used the combination of these two approaches to analyze the driver's response to real-time information in Switzerland. The revealed preference (RP) questionnaire included a question about the respondent's willingness to participate in the second phase of the study, involving a stated preferences (SP) experiment based on the answers in the revealed preference (RP) diary.

As illustrated in Figure 4.7, the questionnaire consists of

- Personal characteristics of the respondents - age and gender of the respondents
- Travel characteristics of the respondents - traffic information sources that the respondents always receive as well as the information they wish to receive
- Driver preference towards the presentation style of traffic information - three different traffic congestion levels were introduced; congested, stop and go and free flow. The respondents were also asked about the information that they prefer the most in familiar and unfamiliar driving conditions. In addition, the respondents had to rank the information presented in terms of understandability, usefulness as well as content detail.
- The hypothetical situation for driver behavior - the respondents were asked to imagine that they were driving in two different driving scenarios: driving in peak periods and driving as part of a leisure trip. In addition, the respondents had to evaluate their choice of response once they received the information in congested, stop and go as well as free flow conditions.

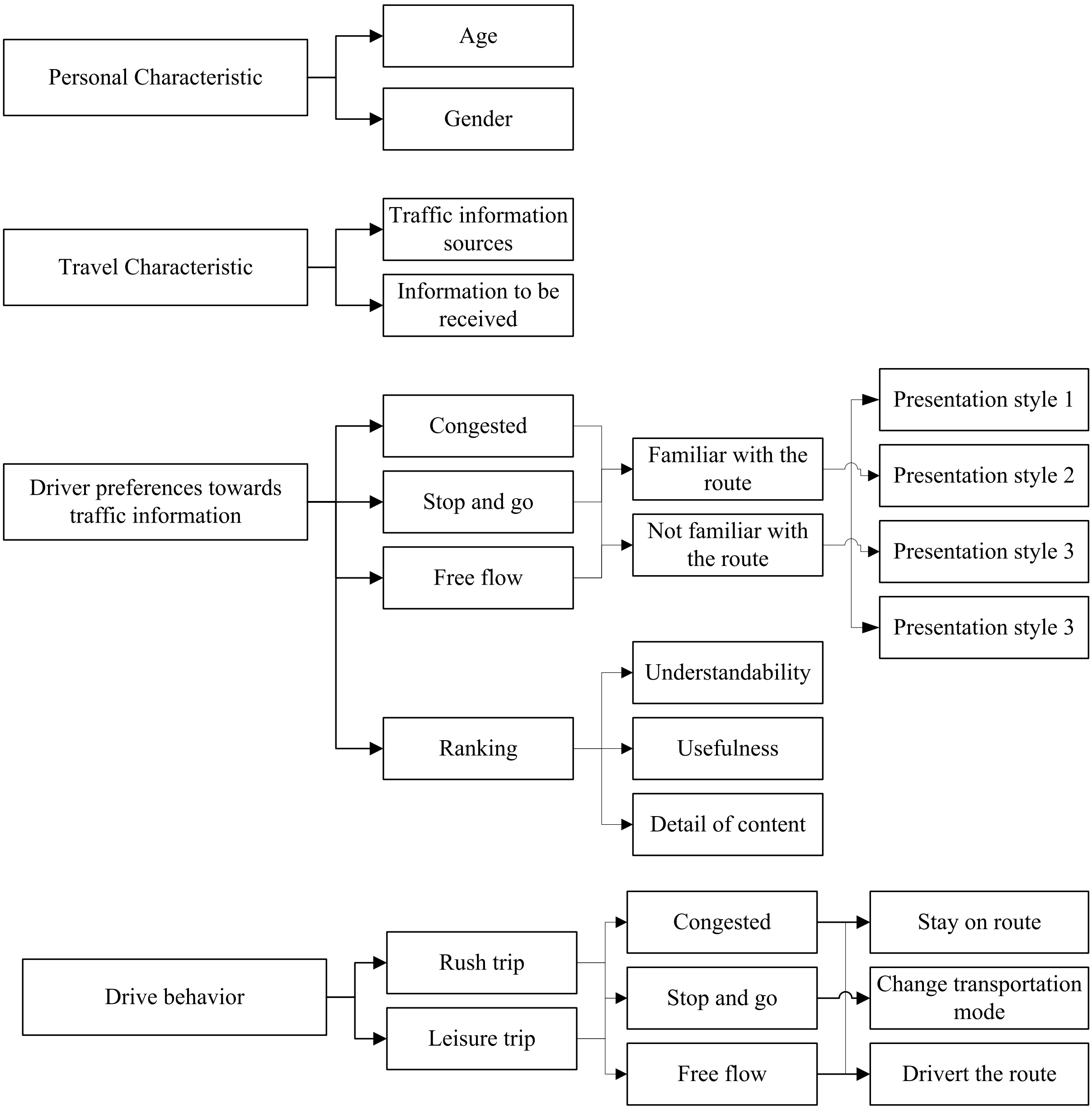


Figure 4. 7 The content of questionnaire

Table 4.2 shows the summary of findings regarding socio-economic characteristics from the literature. It can be seen that many researchers studied some factors such as gender, age, familiarity with road network and frequency of route but much is still unknown. With regard to the influential factors for route choice behavior, the evidence is not clear and some of it is conflicting. For instance, credibility and reliability of VMS showed a significant relationship for route choice behavior. On the other hand, the results of gender, age, income, education level, familiarity with the road network, and frequency of route, time constraint and experience of VMS generated different findings amongst researchers.

The personal characteristic of the respondents include the age, gender and occupation. Four questionnaires with three types of information visualization were distributed to the respondents. The respondents need to choose which type of visualization they prefer the most in a given traffic scenarios. Besides, the respondents were also provided with 5 point scale ratings (1 = best, 5 = worst) to rank how the individual presentation style suits them in terms of understandability, usefulness and detail of contents. The results were analyzed using qualitative and statistical techniques.

Table 4. 2 Socio-economic characteristics and drivers' route choice

Variable	Road type				Socioeconomics characteristic				Trip characteristic				
	Highway	Arterial	Toll road	Not specified	Age	Gender	Income	Education	Route familiarity	Frequency of using the route	Experience with the information	Time Constrain	Credibility of the information
Wardman et al. (1997)	o				o	o			x	x	x	x	o
Adler and Blue (1998)				o					o				
Dia (2002)					o	o	x	x				o	
Peeta and Ramos (2006)	o				o	o	o	o					
Lotan (1997)		o							o		o		
Ka-hung and Wing-gun (2000)			o		o	x	o	x		o			
Abdel-Aty and Abdalla (2005)		o			o								
o – influence route choice x – do not influence route choice													

According to Taylor et al. (2000), a pilot survey is such an important element that excluding it poses great risk to the success of the main survey. At any level of the pilot survey, the survey plan must be revisited or redesigned if necessary. Richardson et al. (1995) also highlight the importance of the pilot survey, and even if a pilot survey is conducted very carefully, there may still remain small problems when researchers conduct the main survey. Therefore, there remains a distinct possibility of the survey containing weaknesses or major problems in the questionnaire if researchers neglect to undertake a pilot survey. There are several important factors for carrying out the pilot survey to examine ambiguities such as wording, layout, consistency, length, time for completion of the questionnaire and so on. For the purpose of this research, a pilot survey was conducted with a small sample (15 respondents) in order to check the ambiguities mentioned above before performing the main survey. In particular, since the self-completion questionnaire method was selected for this study, the wording of the questionnaires needed to be very clear and completion time of the questionnaire needed to be set within acceptable duration for respondents, that being, less than 20 minutes. Based on the respondents' feedback, many words and phrases were modified. In regard to completion time of the questionnaire, the first questionnaire took approximately between15 to 25 minutes to be filled out by most of the respondents and the second questionnaire took under 10 minutes. Therefore the time was considered to be within an acceptable duration for the respondents. Layout and some figures were also improved in order to display the information more clearly and to reduce any misunderstandings.

Table 4. 3 Sample sizes from previous research

Researchers	Sample size	Survey tool	Distribution	Sample size
Richards and McDonald (2007)	SP		2000	4745
Wardman et al. (1997)	SP	Mail back	900	314
Peeta and Ramos (2006)	SP	Interview		248
Dia (2002)	SP/RP	Mail back	490	167

Jou (2001)	SP	Interview	925	296
Feng and Kuo (2007)	SP			493

4.4.3 User data collection

In this study, SP surveys in the form of a questionnaire were developed with the aim to involve more than 100 individual volunteers in the study. The survey was conducted in Munich. The questionnaires were distributed in English and German language. In order to get more effective sample of the target population, two survey platforms were adopted - on-site survey and internet-based survey. The on-site survey was carried out in two days, in a beer garden in Munich. A web content management framework TYPO3 was used as a platform for the internet-based survey. The questionnaire was enclosed with a covering letter described the purpose of the research. We assumed that the respondents would have adequate time to think about the questionnaire.

4.4.4 Tools of statistical analysis

4.4.4.1 Multinomial logistic regression

The data collected from the participants for this study are analyzed using the Statistical Package for Social Sciences 17th version (SPSS). Multinomial logistic regression is typically used to analyze relationships between a non-metric dependent variable and metric or dichotomous independent variables and was applied to analyze the data and test the hypotheses for the study for a number of reasons. Firstly, in order to undertake robust impact analysis, information on the quality of the classification is required. In this respect a probabilistic approach was preferred compared to activation values of artificial neural networks. Multinomial regression was employed in preference to multiple regressions as a categorical dependent variable was of most interest in this study. Multiple regressions have been shown to be inappropriate for such inferences particularly in relation to the assumption of homoscedasticity. Finally, multinomial logistic regression handles non-linearity between independent variables and the dependent categorical model robustly and intrinsically and in a relatively straightforward manner. Even though Bayesian approaches can be employed to develop nonlinear classification and regression models, their derivation and application is often significantly more complicated than multinomial logistic regression.

Multinomial logistic regression models involve nominal response variables in more than two categories and multiple equations. Response variable with k categories will generate k-1 equations. Each of these k-1 equations is a binary logistic regression comparing a group with the reference group. The multinomial logistic regression model is given as:

$$\Pr(y_i = 0) = \frac{1}{1 + \sum_{j=1}^{J} \exp(X_i \ B_j)} \qquad \text{Equation 4.1}$$

and

$$\Pr(y_i = j) = \frac{\exp(X_i \ B_j)}{1 + \sum_{j=1}^{J} \exp(X_i \ B_j)} \qquad \text{Equation 4.2}$$

where for the *i*th individual, y_i is the observed outcome and X_i is a vector of explanatory variables. The unknown parameters β_j are typically estimated by maximum a posteriori (MAP) estimation.

In practice, the quality of the multinomial logistic regression is usually assessed using the *-2 log L* and "pseudo" R^2 indices.

-2 log L is the product of -2 and the log likelihoods of the null model and fitted "final" model. The likelihood of the model is used to test whether all predictors' regression coefficients in the model are simultaneously zero. If the value of *–2 log L* is greater than the critical value of *chi-square* with degrees of freedom (depending on the number of variables in a model), then the null hypothesis is rejected. With respect to the significance level, a 95% or higher confidence level is commonly used (Louviere et al. 2000), p. 52).

Pseudo R^2 - There are three pseudo R^2 values. Logistic regression does not have an equivalent to the R^2 that is found in ordinary least squares (OLS) regression. Ordinary least squares (OLS) is a method for estimating the unknown parameters in a . There are a wide variety of pseudo R^2 statistics which can give contradictory conclusions. Since these statistics do not mean the same as R^2 in OLS regression (the proportion of variance of the response variable explained by the predictors), their interpretation needs a certain caution.

In addition to quantifying the quality of the multinomial regression models the accuracy of each performed classification was also undertaken. This model can be used to predict the probability of falling into one of the available categories of dependent variables on the basis of information of independent variables. Age and gender are regarded as the most important variables. When it concerns the type of visual messages, the size of the images presented on the display becomes an influence factor as it can contribute to augment or reduce the difficulty to read. Small characters can force aged subjects to look longer to the screen to apprehend messages. When characters are larger, the time older drivers need to obtain information from the screen is reduced.

4.4.4.2 Chi-square test

As in Gravetter and Wallnau (2009), p. 607, a chi-square goodness of fit uses sample data to test hypotheses about the shape or proportions of a population distribution. The test determines how well the obtained sample proportions fit the population proportions specified by the null hypothesis. In other words, this test allows us to test whether the observed proportions for a categorical variable differ from hypothesized proportions. A chi-square test for independence uses the frequency data from a sample to evaluate the relationship between two variables in the population (Gravetter and Wallnau 2009) p. 618.

As an application for our analysis, chi-square goodness of fit was used to test whether there is any preference for the traffic information style. Besides, we also test to find whether there is any preference for the driver behavior. On the other hand, chi-square test for independence was used to find any relationship between dichotomous variable, gender and age towards driver behavior as well as relationship between presentation style of traffic information and driver behavior.

The process of chi square test is composed of four different steps:

1. State the hypotheses and select a level of significance. According to the null hypothesis, the two variables are independent.
2. Determine the degrees of freedom and locate the critical region. For *chi-square* test for independence,

$$df = (R-1)(C-1) \qquad \text{Equation 4. 3}$$

where R = the number of levels for one categorical variable
C = the number of levels for the other categorical variable
df = degree of freedom

3. Compute the f_e values and then chi-square
4. Make a decision regarding the null hypothesis and the outcome of the study.

4.4.4.3 Friedman test

Three control variables of the driver satisfaction in terms of understandability, usefulness and level of details were analyzed using Friedman test. By applying the Friedman test, a mean rank was calculated to define the 'winning' variable among understandability, usefulness, reliability and level of details. An indication was made where the smaller the mean rank value, the more important its corresponding variable. Understandability refers to the easiness people can understand the presented information, while usefulness refers to how useful the information would be for a concerned task and level of details refers to the density of presented contents.

Each traffic information style was followed by ranking list and respondents were asked to rank the degree of satisfaction in terms of understandability, usefulness and level of details. The reason why this analysis was performed was to highlight, if applicable, significant differences between the presentation styles. Ranking was used to find which presentation styles was the most favorable one and which one was unfavorable.

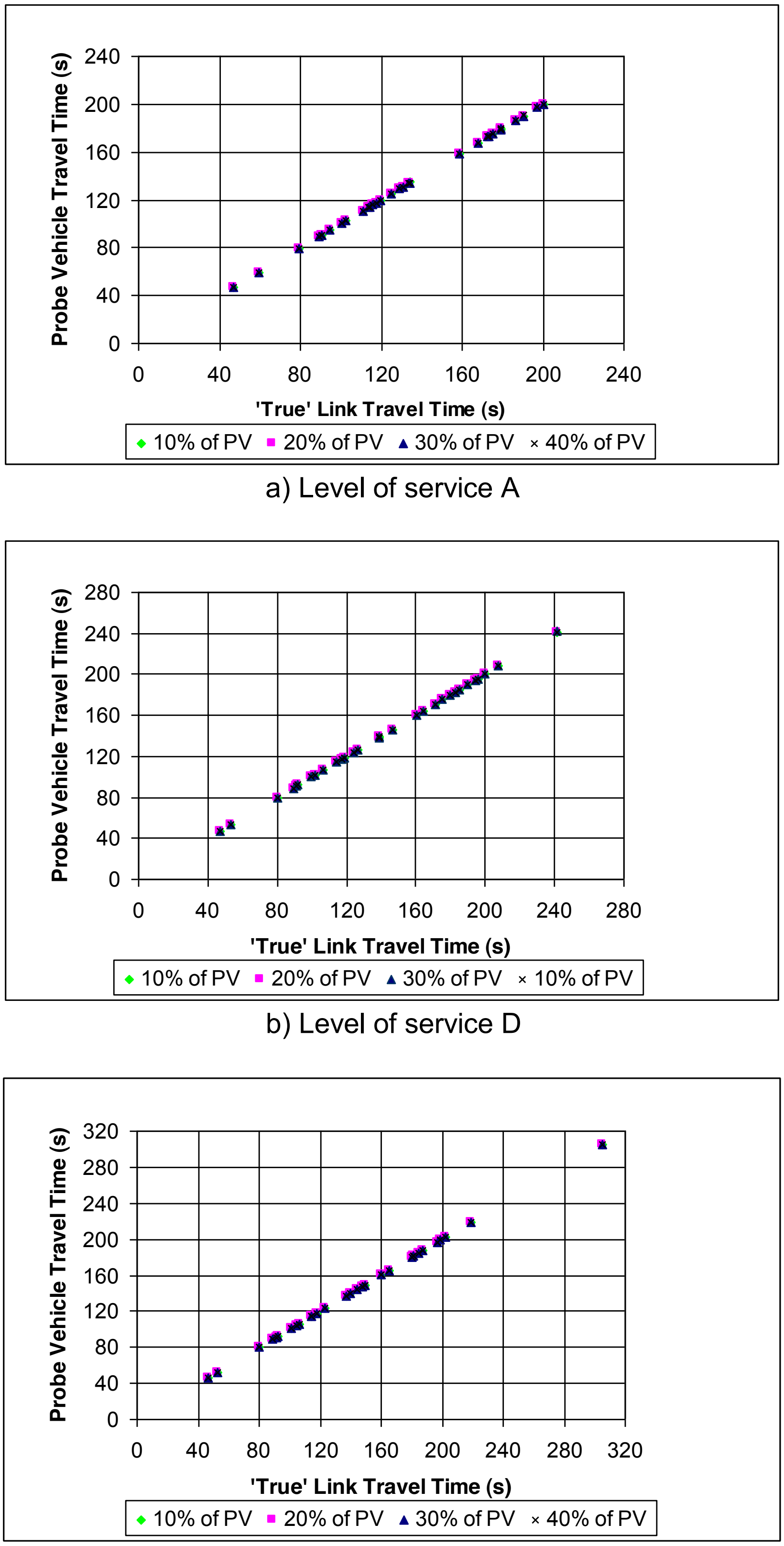
Chapter 5

Implementation of traffic data collection and presentation

5.1. Data analysis of probe vehicle

Our study aims to assess the effectiveness of probe vehicle in providing traffic information (travel time) under various traffic conditions and to develop an analytical congestion visualization system using GIS as a platform. From the data generated by VISSIM or microscopic simulation, we obtained datasets consisting of individual vehicle travel time. Different sample sizes of probe vehicle data were considered. The benchmark is, of course, the 100% data set. However, we only considered 10%, 20%, 30% and 40%, which in terms of number of vehicles are quite significant. Various traffic scenarios were simulated in VISSIM simulation model. The simulation yielded datasets including vehicle identification numbers, travel times and other traffic data for validation. Several statistical analyses for the corresponding data were carried out. The accuracy of the travel time received from probe vehicles under various traffic and probe (market penetration) conditions is essential for the quality of applications on the real road network.

Note that the “true” link travel time is defined as the travel time calculated from all vehicles traversing on the link. This resembles the travel time data obtained from vehicles when they complete the entire route. It is analogous to the 100% probe vehicle market penetration case. At each market penetration case (% probe vehicle), some vehicles are assumed to be probe vehicle. Then travel time determination is basically the average of travel times from all probes. The number of probe vehicles is random, based on percentage of probe. It is natural that travel times from probes vary due to their traffic and driving situations, thus variation in travel times can be seen (as indicated by range and standard deviation of travel times). Since the probe vehicles are re-sampled, the bootstrap of probe vehicles resulted in various numbers of probes in the same percentage of probe vehicles. In this study, the probe vehicles are randomly selected for 500 times, producing various travel times and their variations.



c) Level of service F

Figure 5.1 Average probe vehicle travel time (bootstrapped) versus ‘true’ link travel time

The traffic conditions were broken into 3 traffic situations, depending on their congestion level as indicated by the entering flow into the test network. The average probe vehicle travel time appeared in Figure 5.1 was not the data from a single set of probe vehicles, rather it was the average of bootstrapped travel times. Thus, Figure 5.1 is not intended to show the difference of the average travel time from each set of probes, and the comparison with the 'true' travel time implies the ability of probe vehicles (at a particular percentage of probe vehicles) to give an accurate data, on average. Although we are unable to see the quality of the travel time (in terms of accuracy) of each reported data, Figure 5.1 reveals the effect of the amount of travel time data by probe vehicles (percentage of probes) to the resulting discrepancy of travel times, compared with the 'true' travel time.

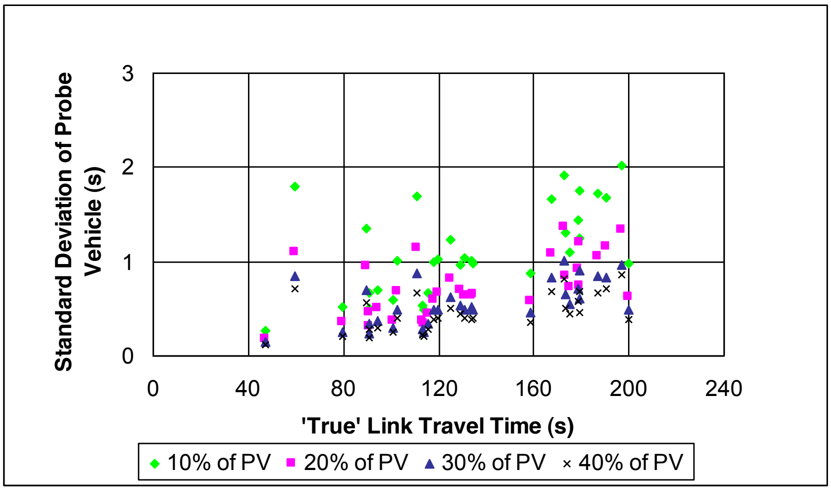
As shown in Figure 5.1 a) to c), the plots of probe vehicle travel time versus 'true' link travel time agree well for different levels of service. This indicates the correlations between accuracy of the travel times and different congestion setting and also implies that the travel time from probe vehicles can be used to represent the 'true' travel time.

The accuracy of the link travel time obtained from the probe data is described by the magnitude of its standard deviation. Suppose that np probe vehicles travel along a link and each of these probe vehicles reports the time required to traverse the link. The standard deviation of the average reported link travel times from the probe vehicles is:

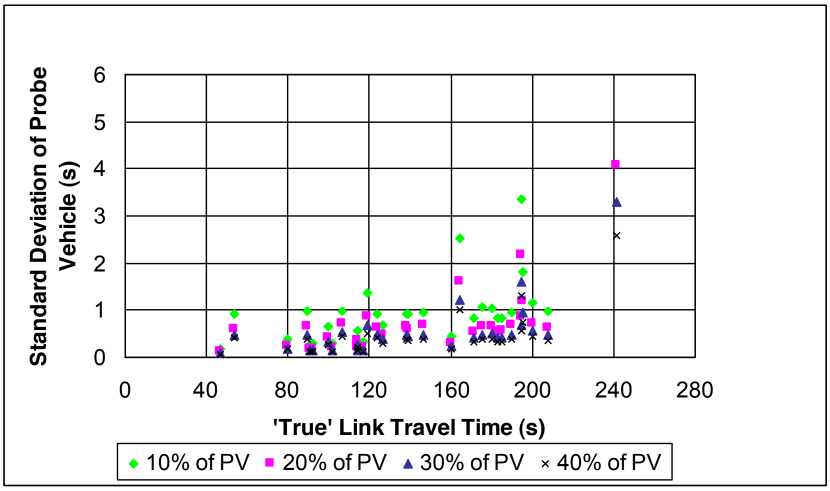
$$\sigma = \frac{\sigma_T}{\sqrt{n_p}} \qquad \text{Equation 5.1}$$

where: σ_T = standard deviation of the mean link travel time reported by the probe vehicles

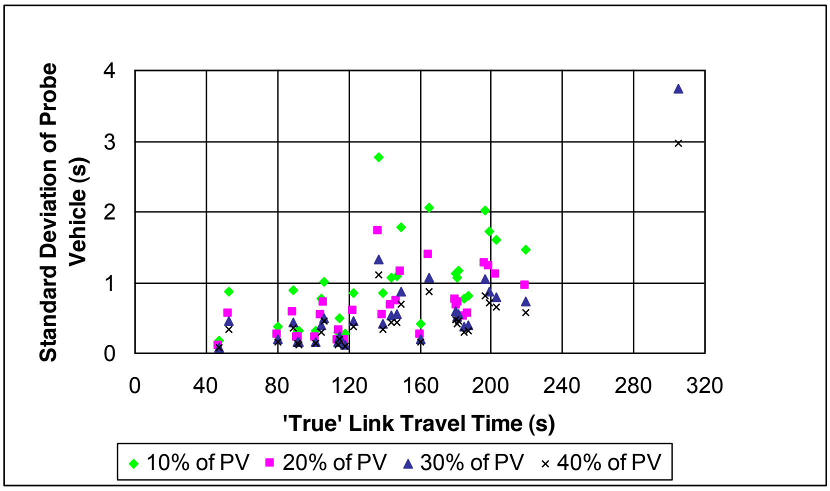
n_p = number of probe vehicles



a) Level of service A



b) Level of service D



c) Level of service F

Figure 5.2 Standard deviation of travel times from probe vehicles compared to 'true' link travel times under various traffic conditions

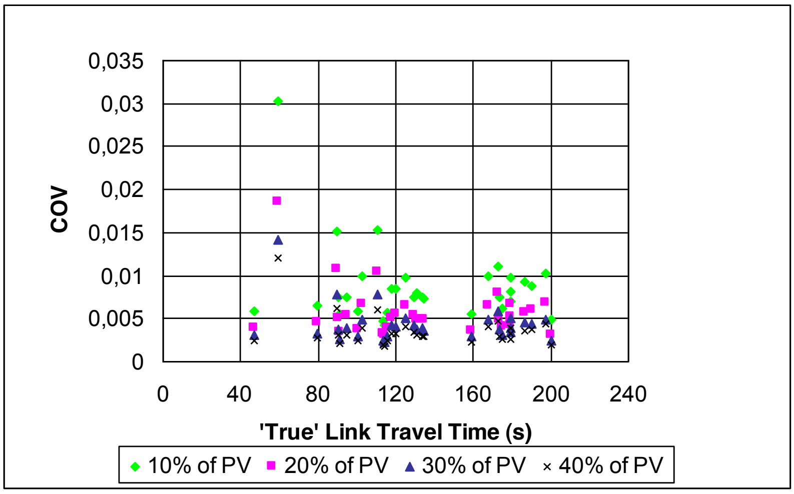
The standard deviation and the average value of the travel times of probe vehicles are shown in Figure 5.2. It is a measure of the average value of the difference between probe vehicle travel time observations and the average value of the 'true' travel time observations. The standard deviation is commonly used to describe the variability of a random variable. The standard deviation increases with the increasing probe vehicle average travel time. Heuristically, a larger number of probe reports imply a better accuracy in travel time prediction. The increase in standard deviation, indicating that there is a greater spread in the 'true' travel times when comparing it with the increasing of the traffic volume. The increases in standard deviation also support the expectation when the traffic generally is cleared during green light and experiences no extraordinary delays. However, if the network has full loads of traffic, traffic can quickly back up into the preceding intersection and take multiple traffic signal cycles to dissipate the queue. In spite of that, the standard deviation primarily depends on the traffic flow and the traffic environment where in case of low traffic flow, most of the drivers can keep their desired speeds and the travel times vary as much as the speed preferences. On the other hand, higher flows make more vehicles hindered and the travel time to a higher extend determined by the surrounding traffic. However, compared probe vehicles with all vehicles, the same tendency of average travel time and variation could be observed although there were few samples of probe vehicles.

Travel times of probe vehicles are less accurate with the increasing traffic volume in the network. Statistically, the increase in standard deviation indicates that the 'true' travel times are more dispersed. Larger variation of standard deviation can be observed with the increasing 'true' travel time while less deviation of travel time is resulted from a large number of probe vehicles as shown in Figure 5.2 a) to c). Other measures of dispersion are the range and variance. Knowing the standard deviation for a set of travel times is important because it is a good indicator for judging the mean as a representation of the "average" response. To further examine the variation (standard deviation) of travel time from the probe vehicles at various traffic conditions, the coefficient of variation is considered which can be expressed as follow:

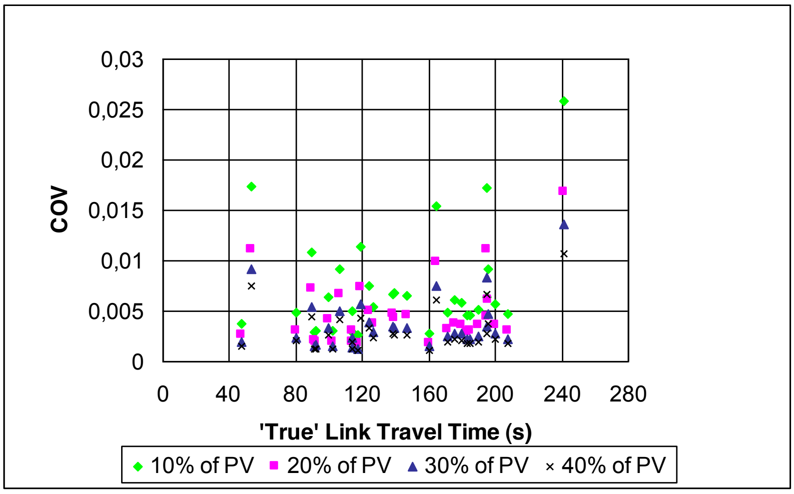
$$COV = \frac{\sigma}{Average} \qquad \text{Equation 5.2}$$

Where, COV = coefficient of variation
σ = standard deviation
Average = average value

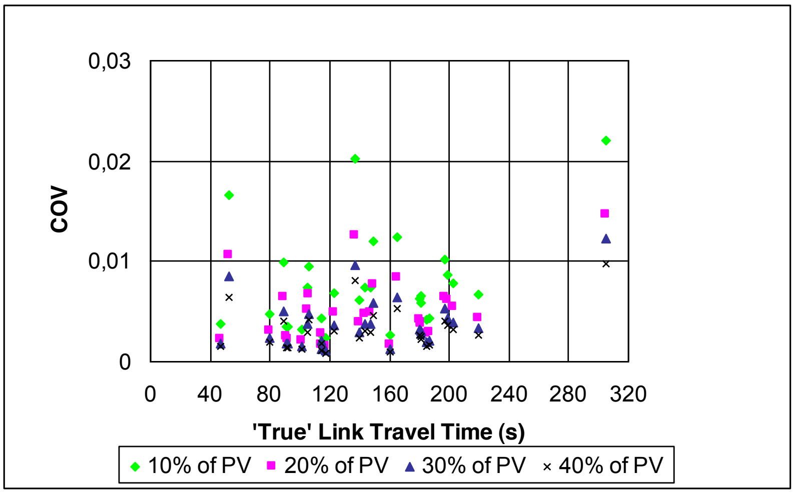
The values of COV are illustrated in Figure 5.3 a) through c) where no patterns can be detected. This implies that the standard deviation (variation) of the travel times reported by probe vehicles is not correlated with the amount of link travel time.



a) Level of service A



b) Level of service D



c) Level of service F

Figure 5.3 Coefficient of variation of the travel time estimates

5.2. Travel time presentation using color-coded network

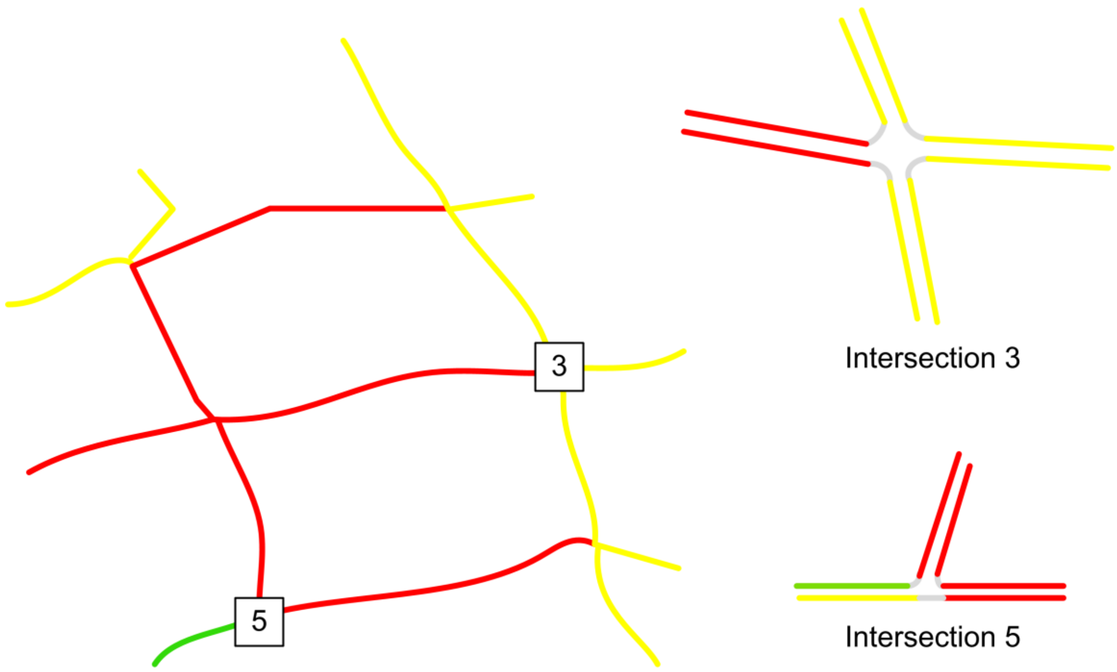
The results in previous section have made it clear that computing the travel time from probe vehicle under various traffic conditions is a reasonable method. Therefore, if only link travel times from probe vehicle could be obtained in the entire network, we could still utilize them as an indicator and report them in a more understandable way. The information presented in different ways may cause different comprehensions and efficiencies. The adage "A picture is worth a thousand words" refers to the idea that complex stories can be described with just a single still image, or that an image may be more influential than a substantial amount of text. It also characterizes the goal of visualization where large amounts of data must be absorbed quickly.

In this study, ArcGIS package was used to display travel time on all road segments. In general, we can build a variety of relational database queries to derive data needed for the production of graphical and tabular travel time reports. However, in this study we considered color-coded maps as the visualization platform for the travel time. These color-coded maps show the variations of travel time along the road segments. VISSIM has one log file which save all information about the created network. The file consists of coordinates of the roads and also other attributes. It is rather straightforward to export the road network from VISSIM to ArcGIS. In this study, an interface was developed to realize the export of road network from VISSIM to ArcGIS. Since ArcGIS was used for visualization of travel times, three indication classes were set in ArcGIS as seen in Table 5.1. If travel time is below 50 seconds, then the network will be green, travel time between 50 and below 150 seconds will appear to be yellow and red will appear if the travel time is more than 150 seconds.

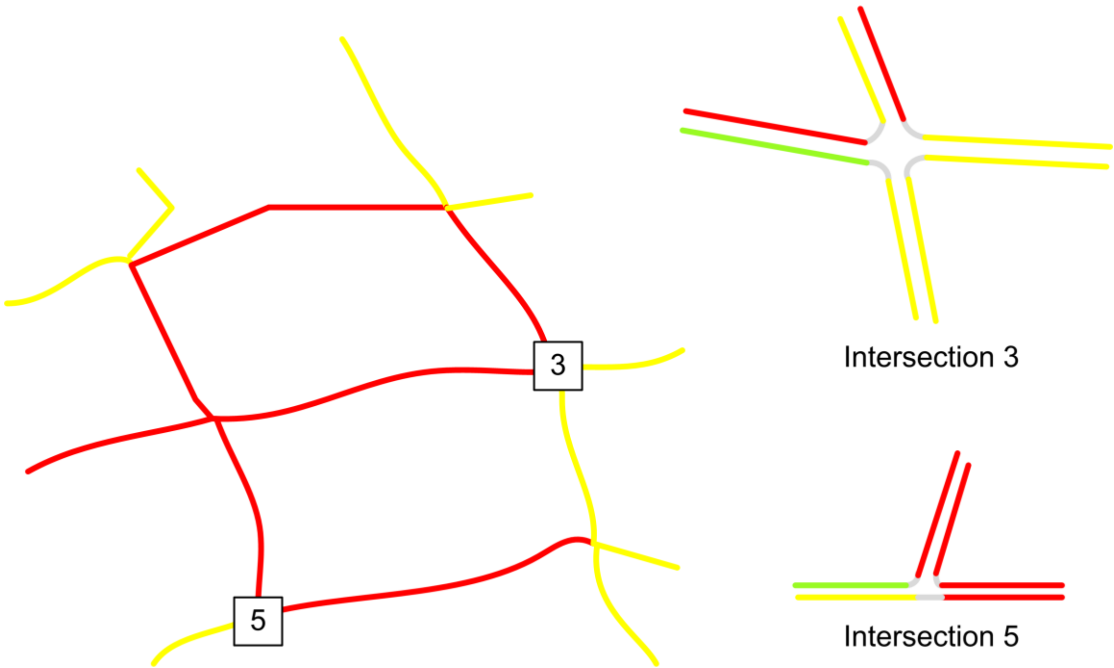
Table 5. 1 Classes of travel time indication in ArcGIS

Travel time (s)	Color
<50	Green
50 - 150	Yellow
>150	Red

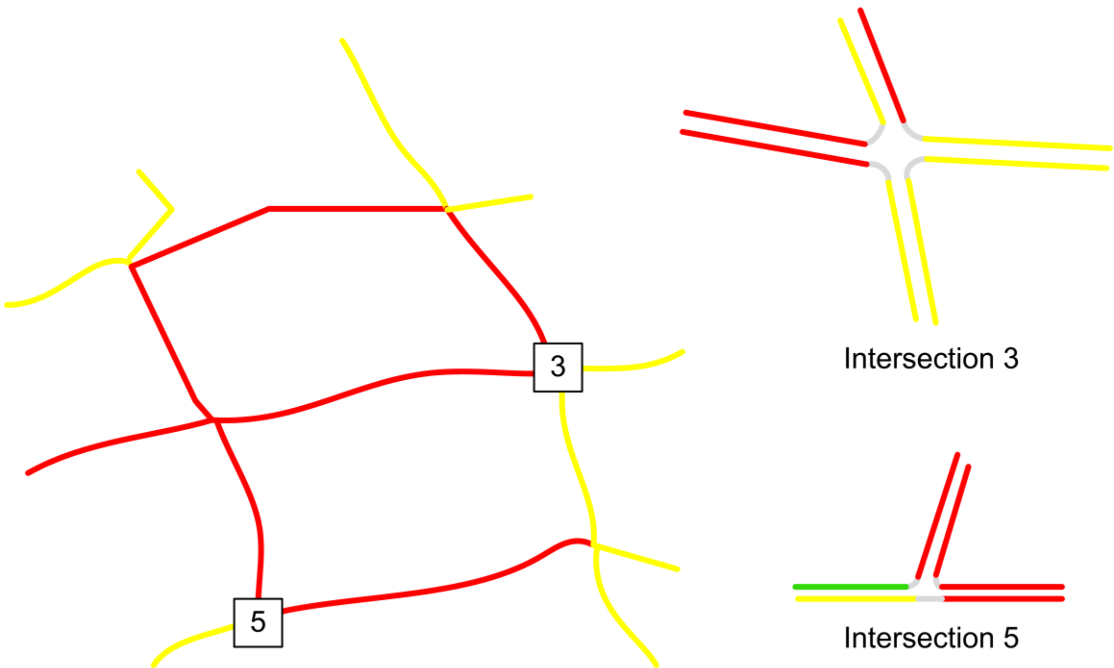
Figure 5.4 a) through c) shows the color-coded road network for three different levels of service. The color-coded network are based on 40% of probe vehicle penetration rate for every level of service. The red depicts the high congestion road which the travel time is more than 150 seconds, yellow for road with less congested (travel time less than 150 seconds) and green for free flow condition (travel time less than 50seconds). Travel times of probe vehicle are less reliable with the increasing traffic volume in the network. The use of colors for the road network with different levels of congestion can make this statement more apparent (see Figure 5.4). During high traffic volumes, the vehicles start to queue to pass the intersection. Some of the vehicles need to wait a few cycles in order to progress through the intersection. Vehicles also start to queue back into the release zones. In the case of low traffic volumes, all vehicles can easily pass through the intersections and the vehicle does not have any obstruction at the end of the network which can cause delay in reaching the destination.



(a) Level of service A



(b) Level of service D



(c) Level of service F

Figure 5.4 The color-coded network in ArcGIS for different level of service for 40% of probe vehicle

One of the interesting issue about probe vehicle as a data source of congestion visualization is the coverage area. It can be seen, in this study, having 40% of probe vehicle from the total vehicles traveling on the streets cover all links for level of service A and D. However, no probe can be detected in high congested network where most of the probe vehicles could not complete their journey until the end of simulation as in Figure 5.4 (c). This condition implies the truth in real world where there is a possibility of having no probe to collect such information in certain links.

5.3. Driver preference towards Information: A case study

This study is deals with color preferences. The colors typically used for representing traffic condition on the map are red for major congestion or stop-and-go driving, yellow for some congestion, traffic has started to slow and green for traffic is flowing at or near normal speeds. A survey was conducted with hypothetical view of the driver. Figure 5.5 depicted the view of the driver towards the information. ‘B’ representing the location of information for ‘in-vehicle’ while ‘A’ representing the location of the information for ‘stationary devices’. Figure 5.6 to Figure 5.9 represent the presentation style used for in vehicle information and Figure 5.10 to Figure 5.12 represent the presentation style used for stationary information.

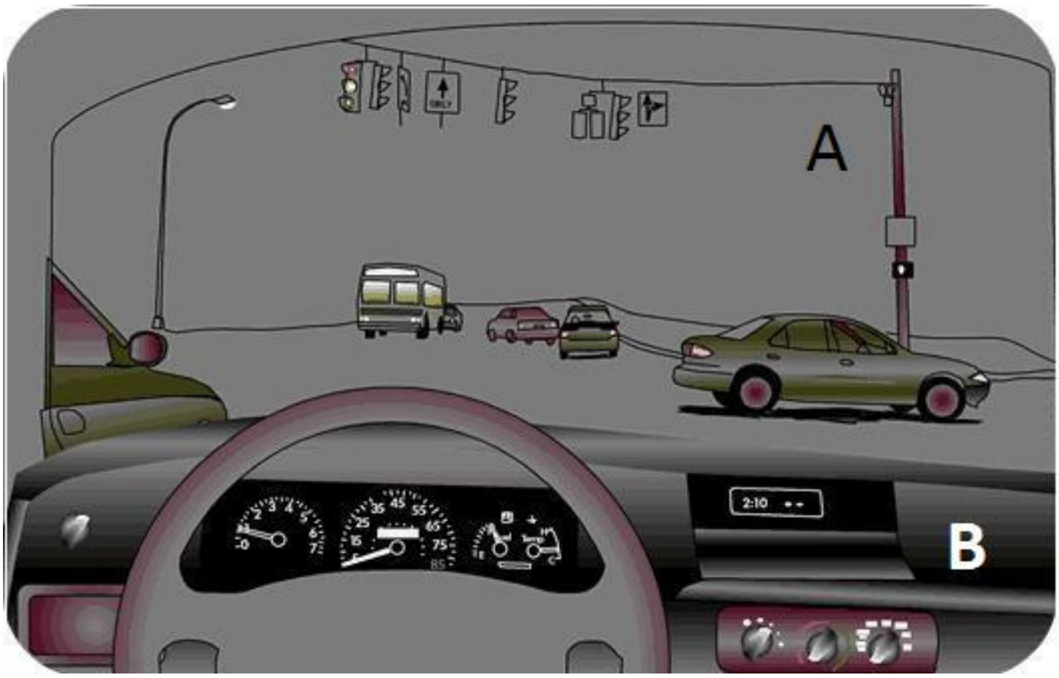


Figure 5. 5 The view of the information from driver’s perspective

Figure 5. 6 Text SMS (Presentation style 1)

Figure 5. 7 Radio (Presentation style 2)

Figure 5.8 Map with buildings (Presentation style 3)

Figure 5.9 Map with streets (Presentation style 4)

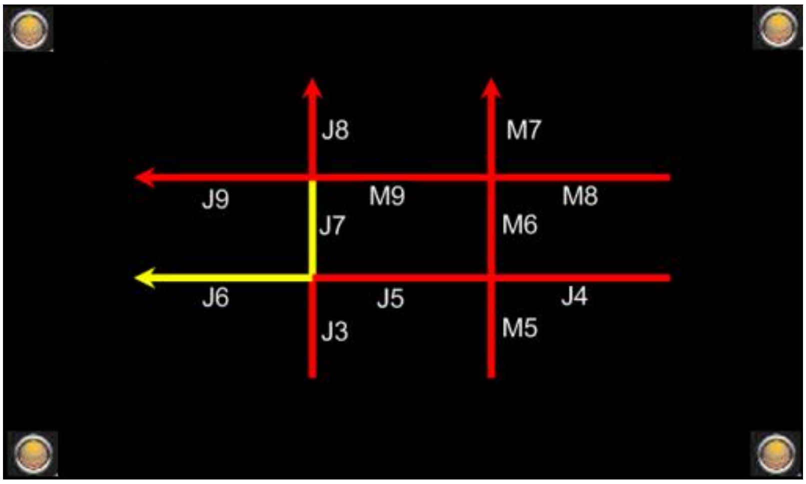


Figure 5. 10 Graphic (Presentation style 1)

Figure 5. 11 Combination of graphic (Presentation style 2)

Figure 5. 12 Text (Presentation style 3)

The development of a system has to be based on the notion of "user-centered design". For our context, this means that the needs and understanding of drivers have to be considered. Some of the primary refinements of the system are identified through a quick usability test that was performed repeatedly throughout the development of the systems. This test serves the purpose of determining if the user has understood a certain aspect of the interface in terms of operation or information format. For example, a quick usability test is conducted to determine how well people could understand the graphic representations of traffic information. The result of this test can help extend and elaborate the symbolization methods, for example, the use of line widths, colored arrows, and dots to represent traffic congestion.

For this kind of test, it is relatively easy to recruit subjects because the only criterion is that they be unfamiliar with advanced driver information systems. We conducted a stated preference survey and the corresponding tests are designed for a case study with in-vehicle devices as well as stationary devices. Following questions are involved in the tests:

1. Which type of presentation style is most preferred by the drivers?
2. Do demographic variables such as gender and age influence drivers' preferences and their behavior?
3. Does presentation style of traffic information have an effect on the drivers' decision?
4. How should traffic information be reasonably presented once drivers retrieve it?

To reduce the variations of information preferences, we segmented the respondents accordingly, for example using gender and age variables. Within each segment the respondents are considered as a random sample from a homogeneous population and the variation is due to differences between segments. The first question that we address in the analysis is whether gender has an impact on driver selection of traffic information. Based on the results of a previous pilot study, our test hypothesis was that there is no significant impact of gender on the preferences of the traffic information. Besides gender, age was also selected as one of the variables where the impact of the age group of drivers upon the selection of traffic information was examined. For practical reasons, the current study was limited to the comparison of two age groups: below 25 years old and above 25 years old.

5.3.1. In-vehicle Information

With a simple underlying question of which presentation style would be chosen by the driver, the major analysis was conducted to distinguish the preference of the drivers towards different types of information according to gender and age. Later, the analyses of preferences were narrowed down to determine whether the presentation style has an effect towards driver behavior in making decision. 100 participants (50 male, 50 female) took part in the study. The subjects were selected from university students, staff of public agencies, housewives and workers of private sectors. Table 5.2 shows the socioeconomic characteristic of the respondents.

Table 5. 2 Personal characteristics of the respondents

Characteristic		Percentage (%)
Gender	Male	50
	Female	50
Age	Below 25	75
	26-45	24
	Above 46	1

Table 5. 3 General travel behavior of the drivers after receiving traffic information

Characteristic	Percentage (%)
Stay in the same route	23
Stop on the way	4
Change transportation mode	21
Divert to your alternate route	51
Other	1

75% of the respondents are below 25 years old. Comparing the gender of the respondents, an equal number of women and men was recruited. In terms of travel characteristic (Table 5.3), 51% of the respondents divert to their alternate route when their route has delay, 21% says they will change transportation mode, but 23% will stay on the current route. Analyzing the current traffic information sources most preferred are Internet, Radio and In-vehicle devices. A group of the drivers (31%) used their personal knowledge as a source of traffic information (see Figure 5.13). The majority of the respondents (96%) considered that traffic information influences their decision making. The most expected travel information received via traffic information sources is travel time delay (84%). Similarly, an average of 75% respondent wants to receive news about accidents and alternate routes. More than a half of the drivers expect to receive information about congestion level as depicted in Figure 5.14.

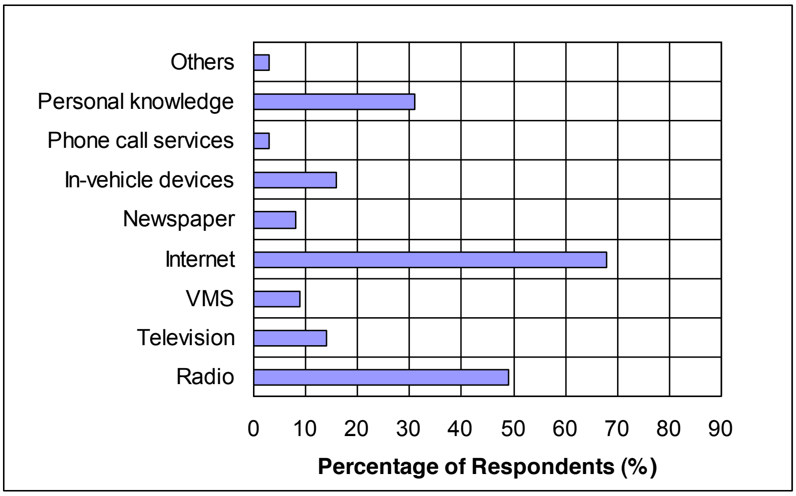


Figure 5. 13 Current traffic information sources

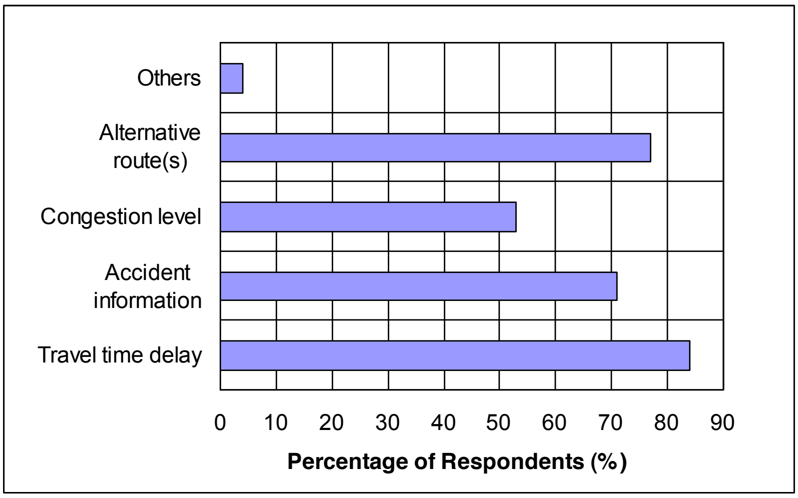


Figure 5. 14 Information expected by drivers

Table 5.4 and 5.5 depict the results of Multinomial logistic regression in 4 situations, stop and go condition and familiar with the route, stop and go condition and not familiar with the route, congested condition and familiar with the route, congested condition and not familiar with the route.

The interpretations of the results are based on value of estimation listed below as in http://www.ats.ucla.edu

- Std. Error - These are the standard errors of the individual regression coefficients for the two respective models estimated.
- Wald - This is the Wald chi-square test that tests the null hypothesis that the estimate equals 0.
- df - This column lists the degrees of freedom for each of the variables included in the model. For each of these variables, the degree of freedom is 1.
- Sig. - These are the p-values of the coefficients or the probabilities that, within a given model, the null hypothesis that a particular predictor's regression coefficient is zero given that the rest of the predictors are in the model. They are based on the Wald test statistics of the predictors, which can be calculated by dividing the square of the predictor's estimate by the square of its standard error

Table 5.4 Multinomial Logistic Regression in Stop and Go condition and (Familiar and Not Familiar with the route)

StopnGo_Familiar		B	Std. Error	Wald	df	Sig.	StopnGo_NotFamiliar	B	Std. Error	Wald	df	Sig.
2.00	Intercept	1.768	.623	8.062	1	2.00	Intercept	.612	.862	.503	1	.478
	[Female=.00]	18.298	.509	1293.559	1		[Female=.00]	-.339	1.461	.054	1	.816
	[Age=.00]	-.881	1.275	.478	1		[Age=.00]	18.004	.884	414.352	1	.000
3.00	Intercept	1.317	.646	4.158	1	3.00	Intercept	2.502	.734	11.602	1	.001
	[Female=.00]	17.228	.638	728.681	1		[Female=.00]	.473	1.259	.142	1	.707
	[Age=.00]	-.285	1.280	.050	1		[Age=.00]	17.121	.531	1040.712	1	.000
4.00	Intercept	1.320	.647	4.163	1	4.00	Intercept	1.865	.757	6.072	1	.014
	[Female=.00]	18.264	.000	.	1		[Female=.00]	.447	1.285	.121	1	.728
	[Age=.00]	-1.585	1.354	1.371	1		[Age=.00]	17.218	.000	.	1	.

Legend: 1 Text SMS, 2 Radio, 3 Map with buildings, 4 Map with streets

Table 5.5 Multinomial Logistic Regression in congested condition (Familiar and Not Familiar with the route)

Congested_Familiar		B	Std. Error	Wald	df	Sig.	Congested_NotFamiliar	B	Std. Error	Wald	df	Sig.
2.00	Intercept	2.078	.694	8.977	1	2.00	Intercept	.776	.843	.848	1	.357
	[Female=.00]	.676	.929	.529	1		[Female=.00]	17.625	.765	530.840	1	.000
	[Age=.00]	1.268	.938	1.826	1		[Age=.00]	16.000	5433.736	.000	1	.998
3.00	Intercept	2.083	.696	8.965	1	3.00	Intercept	2.663	.731	13.278	1	.000
	[Female=.00]	-.138	.956	.021	1		[Female=.00]	17.213	.537	1029.319	1	.000
	[Age=.00]	1.301	.980	1.762	1		[Age=.00]	16.212	5433.736	.000	1	.998
4.00	Intercept	1.594	.720	4.896	1	4.00	Intercept	1.384	.785	3.107	1	.078
	[Female=.00]	.361	.977	.137	1		[Female=.00]	17.427	.000	.	1	.
	[Age=.00]	1.333	1.010	1.743	1		[Age=.00]	15.831	5433.736	.000	1	.998

Legend: 1 Text SMS, 2 Radio, 3 Map with buildings,4- Map with streets

Referring to Table 5.4, for age variable, the log of the ratio of the probabilities (presentation style type 2, 3 and 4) over presentation style type 1 decreases by -0.881, -0.285 and -1.585 respectively. Therefore, in general, the younger the person is, the more she/he will prefer presentation style type 2, 3 and 4 in case of stop and go condition and familiar with the route. This finding is not statistically significant at 95% confident intervals. However, in case of stop and go condition and not familiar with the route, the results do not follow such trend where the older the person is, the more she/he will prefer presentation style type 2, 3 and 4. This finding is statistically significant at 95% confident intervals.

Females are more likely to prefer presentation style type 2, 3 and 4 in case of stop and go condition and familiar with the route. In case of stop and go condition and not familiar with the route, females are more likely prefer presentation style type 3 and 4 while males are more likely prefer presentation style type 2 as compared to presentation style type 1. This finding is not statistically significant.

As indicated in Table 5.5, the same trend could be observed for age variable. On the other hand, for predictor variable such as female, another trend could be observed where males are more likely prefer presentation style type 3 as compared to presentation style type 1 in case of congested condition and familiar with the route. In case of congested condition and not familiar with the route, females are more likely prefer presentation style type 2, 3 and 4.

Further on, we continue our analysis to evaluate the relationship between the demographic variables such as age and gender towards the preferences of traffic information. Our purpose was to determine whether there is a consistent, predictable relationship between the gender and age towards their preferences of traffic information. In other words, we ask whether gender or age of the driver may influence preferences towards difference sources of traffic information. Therefore, our null hypothesis H0 states that there is no relationship while the alternative hypothesis, H1 states that there is a relationship between these two variables. The null hypothesis is rejected if the p value is lower than the level of significance, which is set at 0.05.

Table 5.6 Chi Square of relationship between gender and age towards preferences among presentation styles of traffic information

Variables	Cases	χ^2	df	*p* value
Gender	Congested_Familiar	2.829	3	0.415
	Congested_Not Familiar	2.401	3	0.365
	StopNGo _ Familiar	7.124	3	0.034
	StopNGo _ Not Familiar	0.935	3	0.814
Age	Congested_Familiar	2.356	3	0.553
	Congested_Familiar	0.949	3	0.697
	StopNGo _ Not Familiar	1.939	3	0.562
	StopNGo _ Not Familiar	1.700	3	0.499

As listed in Table 5.6, only in case of stop and go and familiar with the route, the null hypothesis is rejected, since $p < 0.05$. For this case, we found no evidence for relationship between gender and age variables towards preferences among presentation styles of traffic information. For other cases, the null hypothesis is accepted which means that there is a relationship between the demographic variables, i.e. age and gender towards their behavior.

These findings will help us to determine driver's preferences once we know the gender or age of the driver.

Table 5.7 Percentage distribution (%) of ranking values of driver satisfaction in terms of understandability, usefulness and level of details (1 = best, 5 = worst)

	Text SMS			Radio			Map with buildings			Map with streets		
	Understandability	Usefulness	Detail of content	Understandability	Usefulness	Detail of content	Understand -ability	Usefulness	Detail of content	Understandability	Usefulness	Detail of content
Rank 1	10	11	8	32	29	15	44	41	50	37	31	24
Rank 2	17	14	13	39	35	28	26	32	21	32	38	38
Rank 3	42	34	26	16	20	40	13	11	8	14	15	19
Rank 4	21	22	29	8	11	13	7	6	10	9	7	14
Rank 5	10	19	24	5	5	4	10	10	11	8	9	5

For further understanding regarding the driver preferences, three control variables of the driver satisfaction in terms of understandability, usefulness, reliability and level of details as listed in Table 5.7 were analyzed. In general, Map with building is considered as the best alternative for information where 44% of the respondents ranked it to be 'best' in terms of understandability, 41% in terms of usefulness and 50% in terms of detail of content. By applying the Friedman Test, a mean rank was calculated to define the 'winning' variable for text SMS, Radio, Map with building and Map with streets as listed in Table 5.8. An indication was made where the smaller the mean rank value, the more important its corresponding variable. The variable 'understandability' was significantly ranked as the best for Text SMS, Radio and Map with street ($p = <.001$) while the variable 'level of detail' was considered as the favorable one for Map with buildings.

Table 5. 8 The mean rank for measured variable

Measured Variable	Text SMS	Radio	Map with building	Map with streets
Understandability	1.79	1.81	2.03	1.93
Usefulness	1.98	1.93	2.02	1.96
Level of details	2.24	2.26	1.96	2.12

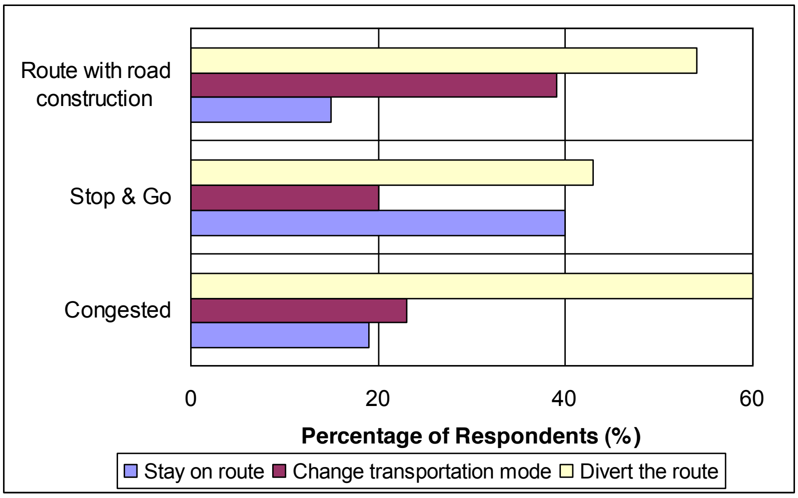


Figure 5. 15 Driver behavior at different congestion levels (during rush trip)

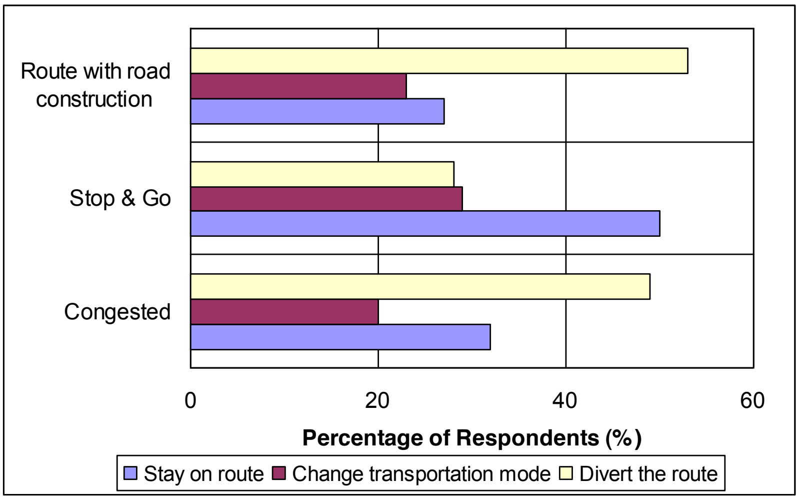


Figure 5. 16 Driver behavior at different congestion levels (during leisure trip)

Figure 5.15 and Figure 5.16 depict driver behavior once they receive information during the rush trip as well as the leisure trip. The driver can choose to stay on the current route, change the route or change their transportation mode. Looking at the results, in general, during leisure and rush trip, the drivers tend to divert the route when they are trapped in congestion. However, in stop and go condition, the drivers tend to stay on route. Besides, comparing two different cases; having a rush trip or leisure trip, the willingness to stay on the current route is much higher in leisure trip.

When performing a statistical analysis, a question was raised for the hypothesis test whether there are any preferences among the three possible behavior, divert the route, stay on route and change transportation mode.

H_0: In the general population, there is no preference for any specific behavior. Therefore, the three possible behavior are selected equally

H_1: In the general population, one or more of the behavior is preferred over the others.

Table 5.9 Chi Square for testing whether there are any preferences among driver behavior

	Mean	Std. Deviation	χ^2	df	*p* value
StopNGo_RushTrip	2.020	0.898	8.060	2	0.018
Congested__RushTrip	1.680	0.723	16.340	2	0.000
Congested_LeisureTrip	2.270	0.814	12.740	2	0.002
StopNGo_LeisureTrip	1.790	0.868	13.460	2	0.001

As listed in Table 5.9, during leisure trip, in case of congested or stop and go route, the null hypothesis is rejected, since $p < 0.05$. Therefore, in the general population, one or more of the behavior is preferred over the others. However, there are significant differences among these three behavior, with some selected more often and other less often would be expected by chance .The same trend of observation can also be seen for rush trip condition with congestion, $\chi 2(2) = 16.340$ $p \leq 0.001$. However, during rush trip with stop and go condition, the null hypothesis cannot be rejected. The drivers select the behavior after receiving the information equally.

It is somehow interesting to evaluate the relationship between the demographic variables such as age and gender towards the driver behavior. For this version of H0, the data is viewed as a single sample with each individual measured on two variables. For this section of analysis, we consider to determine whether there is a consistent, predictable relationship between the gender and the driver behavior and also the age and the driver behavior. The null hypothesis, H0 states that there is no relationship. The alternative hypothesis, H1 states that there is a relationship between these two variables.

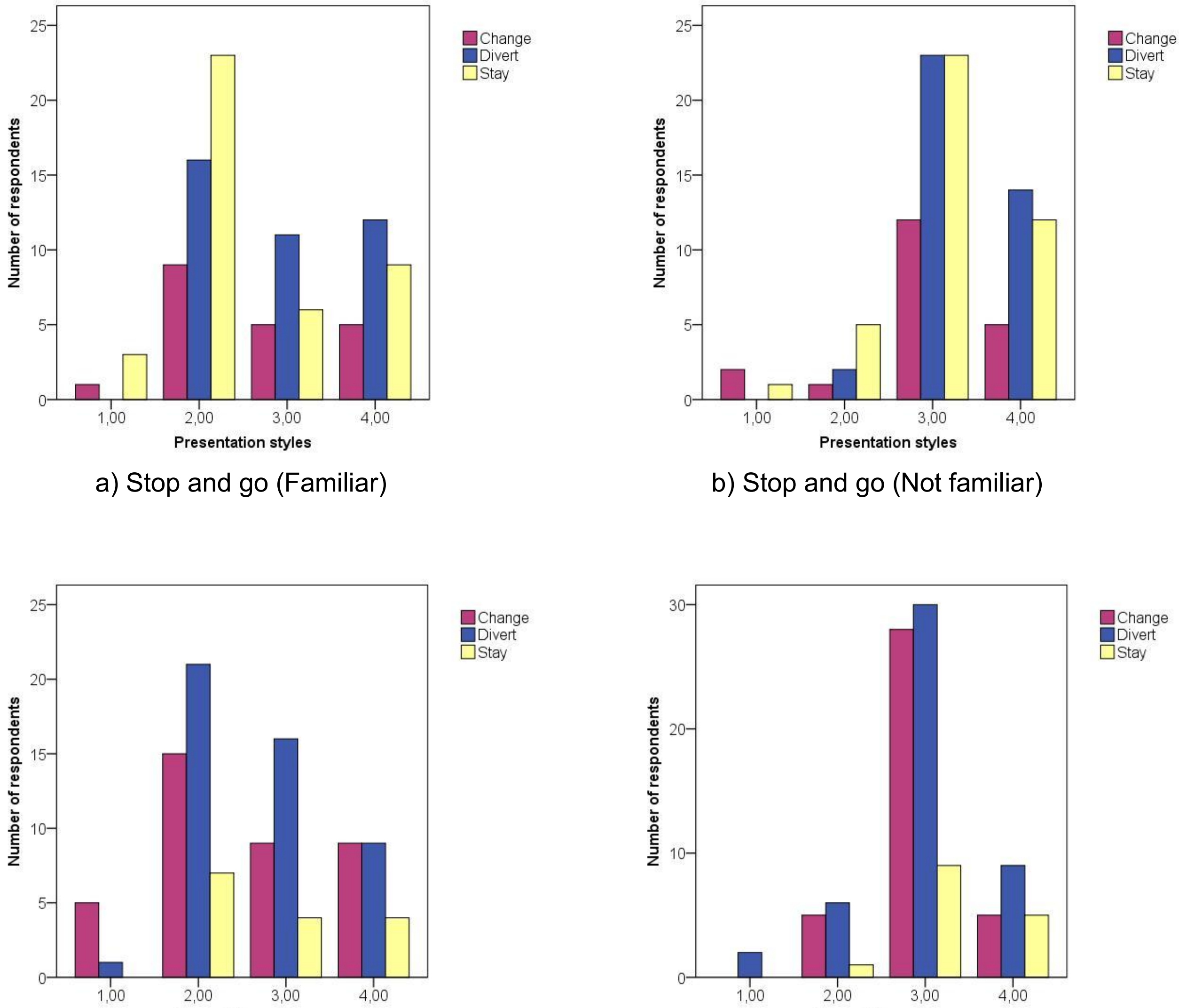
Table 5.10 Chi Square of relationship between gender and age towards driver behavior

Variables	Cases	χ^2	df	*p* value
Gender	StopNGo_RushTrip	1.045	2	0.591
	Congested__RushTrip	3.542	2	0.166
	StopNGo_LeisureTrip	0.697	2	0.705
	Congested_LeisureTrip	1.545	2	0.459
Age	StopNGo_RushTrip	0.017	2	0.992
	Congested__RushTrip	0.580	2	0.748
	StopNGo_LeisureTrip	0.994	2	0.601
	Congested_LeisureTrip	0.987	2	0.611

Table 5.10 presented the Chi Square of relationship between gender and age towards driver behavior. For all cases, the null hypothesis is accepted and a conclusion is made that there is no relationship between the demographic variables age and gender towards the behavior. These findings are contradicted to Liu et al. (2007) where driver's age was an important consideration in advanced traveler information display design because the number of elderly drivers continues to increase. Besides, previous study of Dingus et al. (1997) showed that older drivers experience more attention demand. Our findings do not provide evidence that gender and age matters in predicting the driver behavior.

When analyzing whether the presentation style has an effect on the driver decision, again, a chi square test was used. Figure 5.17 and Figure 5.18 depicted the results while Table 5.11 illustrates the Chi square figure. Our Null and alternative hypotheses are:

H_0: The behavior of the driver is not associated with traffic information presentation style
H_1: The behavior of the driver is associated with traffic information presentation style.



a) Stop and go (Familiar)

b) Stop and go (Not familiar)

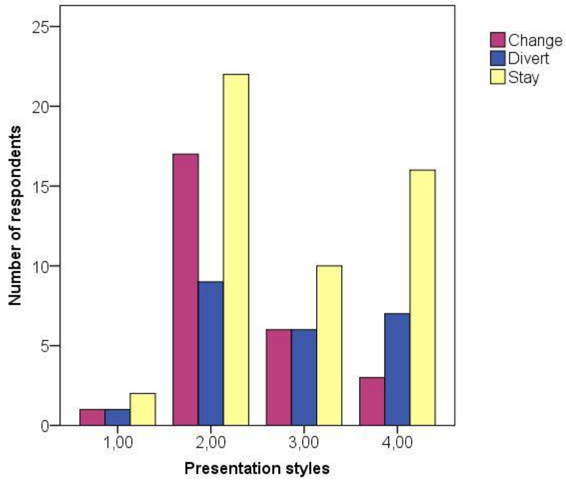
c) Congested (Familiar)

d) Congested (Not familiar)

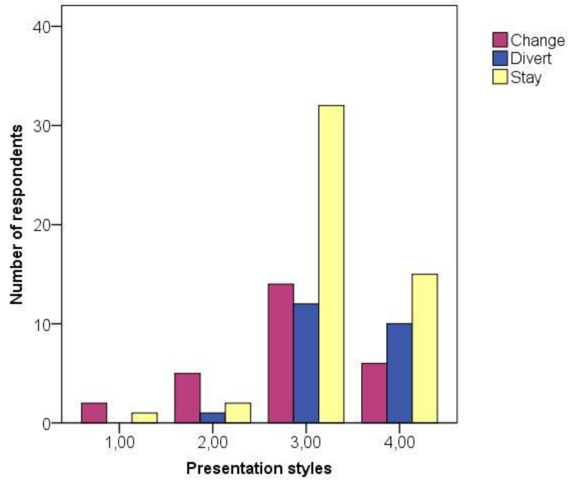
Legend: 1 Text SMS, 2 Radio, 3 Map with buildings,4 Map with streets

Figure 5.17 Drivers' preferences on the information presentation style (Rush trip)

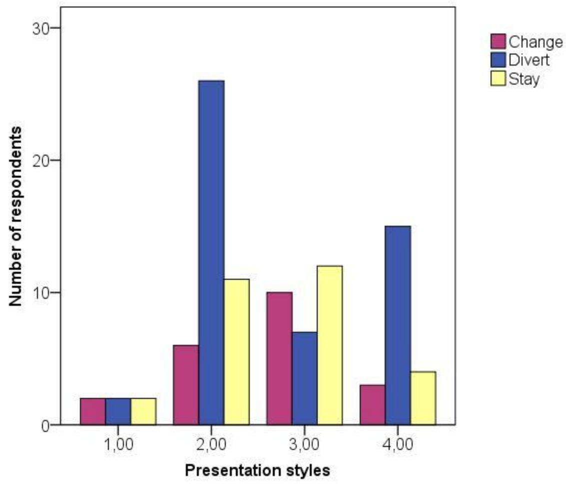
The results were analyzed using control effect which is the trip purpose (rush trip or leisure trip) with an alpha level of .05. Only in case of congested and familiar with the route the null hypothesis is rejected, since $p < 0.05$. Looking at the results of driver behavior once receiving the information, during rush trip, the drivers prefer to divert. The willingness to stay on the current route is much higher in leisure trip. In rush trip and whether the drivers are familiar or not familiar with the route, the null hypothesis cannot be rejected, since $p>0.05$. A conclusion is made that the behavior of the driver is not associated with the presentation style of traffic information. A chart illustrates the pattern of responses well. Examining the pattern of numbers it is noted that in case of familiar with the route, more drivers prefer having traffic information that can be seen visually Map with buildings and in case of familiar with the route, more drivers prefer to have radio as their sources of traffic information. In case of leisure trip, the same pattern of results could be seen.



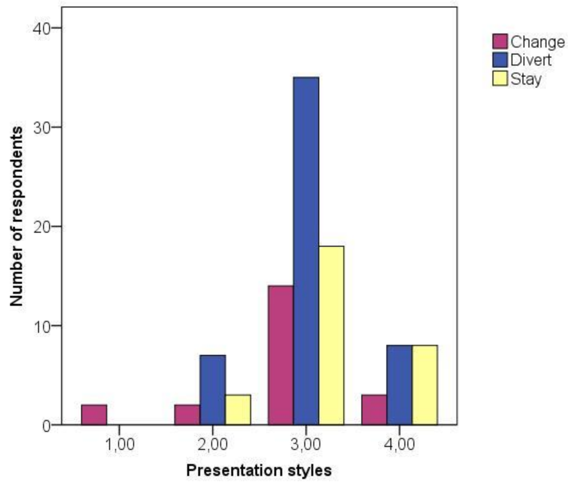
a) Stop and go (Familiar)



b) Stop and go (Not familiar)



c) Congested (Familiar)



d) Congested (Not familiar)

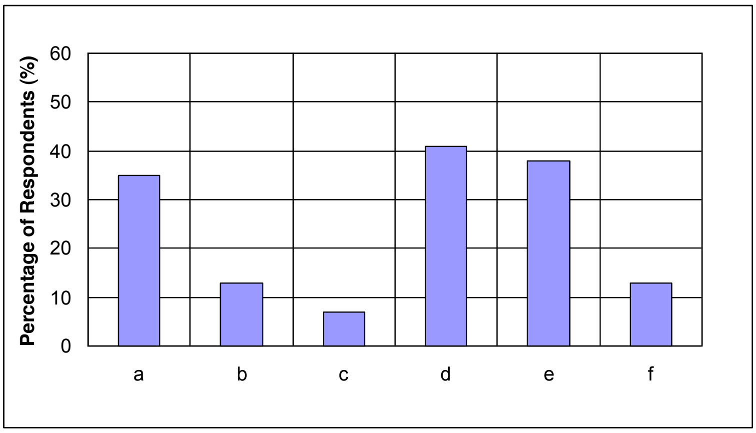
Legend: 1 Text SMS, 2 Radio, 3 Map with buildings, 4 Map with streets
Figure 5.18 Drivers' preferences on the information presentation style (Leisure trip)

Table 5.11 Chi Square of relationship between presentation style and driver behavior

Cases	Cases	χ^2	df	*p* value
Rush trip	Stop and Go (Familiar)	6.113	6	0.276
	Stop and Go (Not Familiar)	6.628	6	0.367
	Congested (Familiar)	6.689	6	0.307
	Congested (Not Familiar)	5.415	6	0.420
Leis ure trip	Stop and Go (Familiar)	5.250	6	0.453
	Stop and Go (Not Familiar)	10.186	6	0.142

Congested (Familiar)	13.771	6	0.027
Congested (Not Familiar)	9.44	6	0.219

Figure 5.19 depicts the distribution of various reasons given by the drivers for not changing their route. The two main reasons are a) they think it will be faster to stay on current route and b) they do not think the alternative choices will be faster. This results are consistent with (Lee et al. 2004) and this might be the other explanation why more drivers would rather to choose to stay on route in both rush and leisure trip.



a. I am afraid that I will get lost if I deviate from my planned route
b. I do not feel safe driving in unfamiliar areas
c. I do not trust the information provided
d. I think it will be faster to stay on my current route
e. I do not think the alternative choices will be even faster((alternative route is provided)
f. Additional

Figure 5.19 Reasons for not adjusting the route

5.3.2. Stationary information

This section is dedicated to analyze the driver behavior towards different presentation styles of traffic information in case of stationary information. 102 participants (57 male, 45 female) took part in the study. The subjects were selected, ranging from university students and workers to housewives and workers of private sectors. Table 5.12 listed the personal characteristic of the respondents. In general, when the drivers discovered delay on their current route, they will divert to alternatives route, given that the information of alternative routes is available. This was proved by the results where 57.8% of the respondents would divert the route once getting the information while 27.5% stay on route without doing anything (Table 5.13).

Three presentation styles of traffic information on VMS panel were introduced namely, graphic, text and combination of graphic and text. The analyses on the driver preference towards the information presentation style of traffic information were categorized into two cases: familiar and not familiar with the route.

Table 5. 12 Personal characteristics of the respondents

Characteristic		Percentage (%)
Gender	Male	55.9
	Female	44.1
Age	Below 25	21.6
	26-45	59.8
	Above 46	18.6

Table 5. 13 General travel behavior of the drivers after receiving traffic information

Characteristic	Percentage (%)
Stay in the same route	27.5
Stop on the way	4.9
Change transportation mode	8.8
Divert to your alternate route	57.8
Other	1

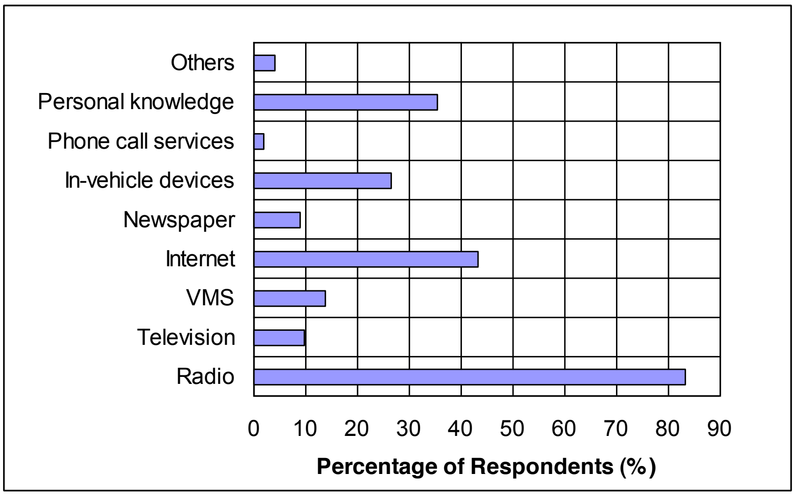


Figure 5. 20 Current traffic information sources

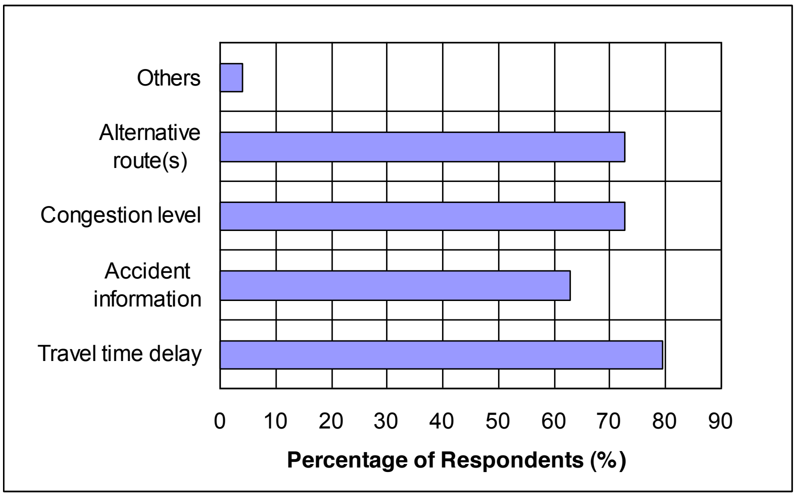


Figure 5. 21 Information expected by drivers

As shown in Figure 5.20, 83.3% of the respondents use radio as their traffic information sources followed by internet (43.1%), personal knowledge (35.3%) and in-vehicle devices (26.5%). 79.4% of respondents would like to have travel time delay as one of the information while 62.7% would like to have accident information as depicted in Figure 5.21.

Table 5.14 Multinomial Logistic Regression in Stop and Go Condition and (Familiar and Not Familiar with the route)

StopnGo_Familiar		B	Std. Error	Wald	df	Sig.	StopnGo_NotFamiliar	B	Std. Error	Wald	df	Sig.
2.00	Intercept	1.918	.828	5.371	1	.020	Intercept	1.762	.734	5.767	1	0.016
	[Female=.00]	.247	.551	.201	1	.654	[Female=.00]	-.043	.593	.005	1	0.952
	[Age=.00]	-1.072	.807	1.767	1	.184	[Age=.00]	-.148	.711	.043	1	0.835
3.00	Intercept	1.046	.939	1.241	1	.265	Intercept	-.322	1.023	.099	1	0.753
	[Female=.00]	-.646	.627	1.060	1	.303	[Female=.00]	-.133	.730	.033	1	0.856
	[Age=.00]	-.472	.932	.257	1	.612	[Age=.00]	.703	.998	.496	1	0.481

Legend: 1 Graphic, 2 Combination of graphic and 3 Text

Table 5.15 Multinomial Logistic Regression in Congested Condition (Familiar and Not Familiar with the route)

Congested_Familiar		B	Std. Error	Wald	df	Sig.	Congested_NotFamiliar	B	Std. Error	Wald	df	Sig.
2.00	Intercept	1.895	.840	5.096	1	.024	Intercept	2.523	.935	7.286	1	0.007
	[Female=.00]	.183	.580	.099	1	.753	[Female=.00]	-.630	.735	.735	1	0.391
	[Age=.00]	-.951	.816	1.358	1	.244	[Age=.00]	-.267	.846	.100	1	0.752
3.00	Intercept	1.182	.917	1.660	1	.198	Intercept	1.318	1.047	1.585	1	0.208
	[Female=.00]	-.459	.621	.546	1	.460	[Female=.00]	-.929	.809	1.320	1	0.251
	[Age=.00]	-.336	.903	.138	1	.710	[Age=.00]	.081	.971	.007	1	0.934

Legend: 1 Graphic, 2 Combination of graphic and 3 Text

As referred to Table 5.14, for age variable, the log of the ratio of the probabilities (presentation style 2 and 3) over presentation style 1 will be decreased by -1.072 and -0.472 respectively. Therefore, in general, the younger the person is, the more she/he will prefer presentation style 2 and 3 in case of stop and go condition and familiar with the route. This finding is not statistically significant at 95% confident intervals. In case of stop and go condition and not familiar with the route, the results do not follow such trend where the older the person is, the more she/he will prefer presentation style 3. This finding is statistically significant at 95% confident intervals.

Females are more likely to prefer presentation style 2 in case of stop and go condition and familiar with the route. In case of stop and go condition and not familiar with the route, males are more likely prefer presentation style 2 and 3 as compared to presentation style 1. This finding is not statistically significant. In other words, male driver, would rather choose to have combination of ‘graphic and text information’ as compared to text information during congested and ‘stop and go’ condition. As the congestion increased which also led to the diminishing of level of service, the tendency of female and male drivers to choose ‘combination of graphic and text information’ is increased in case of not familiar with the route.

In case of congested condition predictor variable such as female, another trend could be observed where males are more likely prefer presentation style 2 as compared to presentation style 1 in case of congested condition and familiar with the route. In case of congested condition and not familiar with the route, females are more likely prefer presentation style 2 and 3. These findings are not statistically significant.

Further on, we continue our analysis to determine whether there is a consistent, predictable relationship between the gender and age towards their preferences of traffic information. We stated our null hypothesis H0 as there is no relationship while the alternative hypothesis, H1 states that there is a relationship between these two variables.

Table 5.16 Chi Square of relationship between gender and age towards preferences among presentation styles of traffic information

Variables	Cases	χ^2	df	*p* value
Gender	Congested_Familiar	2.232	2	0.328
	Congested_Not Familiar	1.403	2	0.489
	StopNGo _ Familiar	3.675	2	0.160
	StopNGo _ Not Familiar	0.075	2	0.963
Age	Congested_Familiar	2.378	2	0.292
	Congested_Not Familiar	0.401	2	0.813
	StopNGo _ Familiar	2.696	2	0.239
	StopNGo _ Not Familiar	1.340	2	0.512

As shown in Table 5.16, in all cases, the null hypothesis is accepted, since $p>0.05$. This means that there is a relationship between the demographic variables, i.e. age and gender towards their behavior. These findings will help us to determine driver’s preferences once we know the gender or age of the driver.

Again, we continue the analysis to further understanding regarding the driver preferences, again, three control variables of the driver satisfaction in terms of understandability, usefulness, reliability and level of details as listed in Table 5.17 were analyzed. In general, 'combination of graphic and text information' is considered as the best alternative for information where 30% of the respondents ranked it to be 'best' in terms of understandability, 35% in terms of usefulness and 28% in terms of detail of content.

Table 5.17 Percentage distribution (%) of ranking values of driver satisfaction in terms of understandability, usefulness and level of details (1 = best, 5 = worst)

	Graphic			Combination			Text		
	Understand ability	Usefulness	Detail of content	Understand ability	Usefulness	Detail of content	Understandab ility	Usefulness	Detail of content
Rank 1	23	20	12	30	35	28	32	21	23
Rank 2	23	36	35	35	35	22	24	24	15
Rank 3	34	28	32	26	16	29	20	29	40
Rank 4	14	12	14	5	9	14	17	24	16
Rank 5	7	4	4	3	5	3	8	1	2

Further statistical analysis of the test results was conducted with SPSS 17.0. Table 5.18 illustrates the distribution of ranking values in terms of understandability, usefulness and detail of content. By applying the Friedman-Test, an indication was made where the smaller the mean rank value, the more important its corresponding variable. The variable 'understandability' was significantly ranked as the best for text information (p= <.001) while the variable 'usefulness' was considered as the favorable one for 'combination of graphic and text'.

Table 5.18 The mean rank for measured variable

Measured Variable	Graphic map	Combination of graphic and text	Text message
Understandability	2.06	1.91	1.95
Usefulness	1.90	1.90	2.04
Level of details	2.04	2.20	2.01

Either the congestion level using graphic or the congestion information using text will impose a large impact on the drivers' decision making. The results rather suggest that one of the reasons for drivers to choose information displayed by 'combination of graphic and text' is that the display is a combination of all important variables.

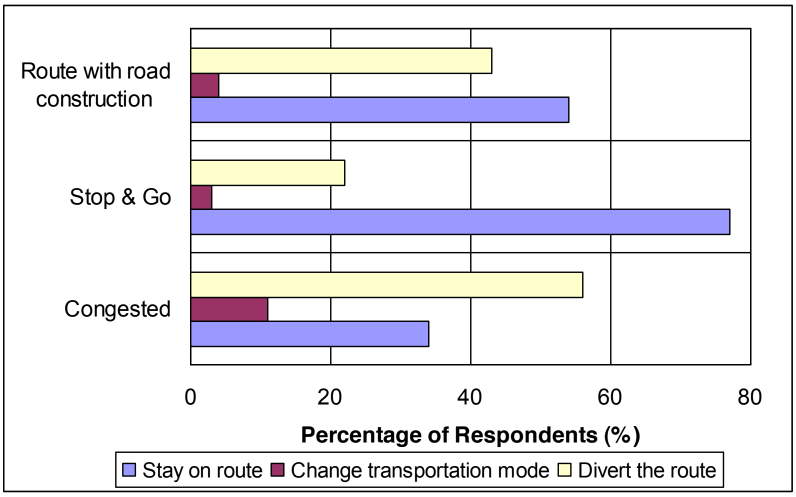


Figure 5. 22 Driver behavior at different congestion levels (during rush trip)

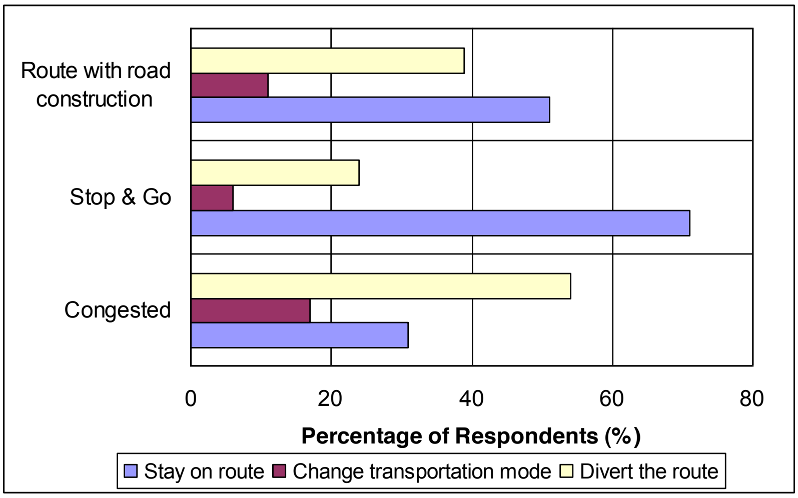


Figure 5. 23 Driver behavior at different congestion levels (during leisure trip)

Figure 5.22 and Figure 5.23 depict the driver behavior at different levels of congestion. Two different cases were defined: during a rush trip (to school or work) and during a leisure trip (shopping or holiday). The respondents were asked about their behavior once they receive the traffic information on congested route, 'stop and go' route and a road with construction work. As shown, on a road with construction and 'stop and go' conditions, the drivers tend to stay on the current route while in the case of a congested route, drivers prefer to divert. This finding is different from the previous explanation where 57.8% of the respondents would divert from the route upon receipt of the information regardless of traffic condition. This may be explained by the different levels of congestion scenarios and whether the information of finding alternative routes is accessible or not. When comparing a rush trip with a leisure trip, the willingness to stay on the current route is much higher with a leisure trip.

A question was raised when performing a statistical analysis for the hypothesis test whether there are any preferences among the three possible behavior, divert the route, stay on route and change transportation mode.

H_0: In the general population, there is no preference for any specific behavior.
H_1: In the general population, one or more of the behavior is preferred over the others.

Table 5.19 Chi Square for testing whether there are any preferences among driver behavior

	Mean	Std. Deviation	χ^2	df	*p* value
StopNGo_RushTrip	2.451	0.863	65.706	2	0.000
Congested__RushTrip	1.775	0.889	20.529	2	0.000
Congested_LeisureTrip	1.775	0.922	31.118	2	0.000
StopNGo_LeisureTrip	2.539	0.829	86.882	2	0.000

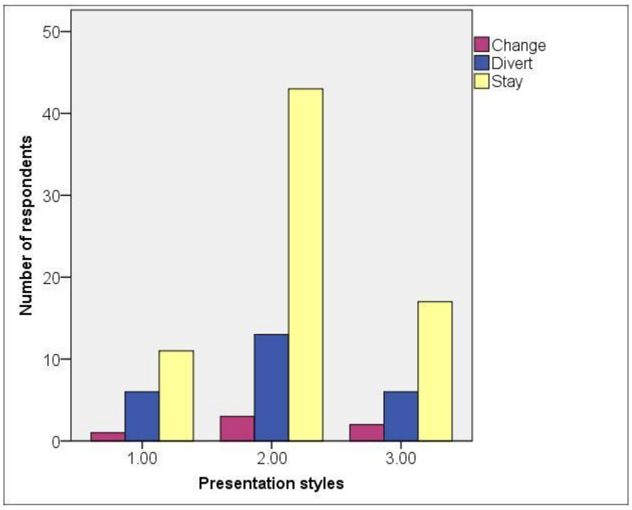
As listed in Table 5.19, in all cases, we found there are no significant differences among these three behavior, with some selected more often and other less often would be expected by chance. Further, we narrowed down the analysis to evaluate the relationship between the demographic variables such as age and gender towards the driver behavior. The null hypothesis, H_0 states that there is no relationship. The alternative hypothesis, H_1 states that there is a relationship between these two variables.

Table 5.20 Chi Square of relationship between gender and age towards driver behavior

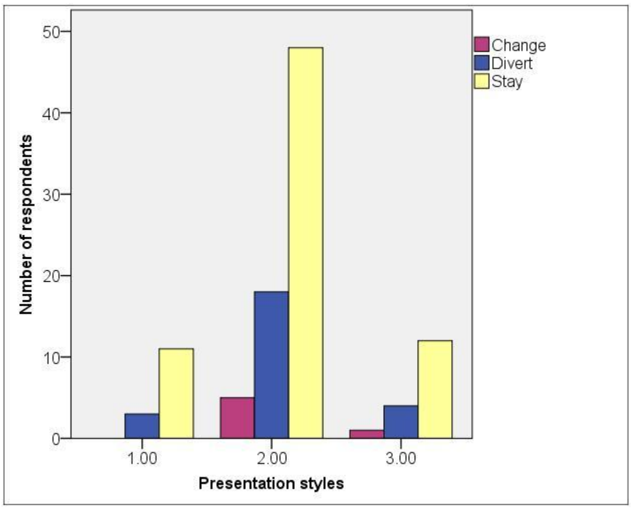
Variables	Cases	χ^2	df	*p* value
Gender	StopNGo_RushTrip	1.045	2	0.591
	Congested__RushTrip	3.542	2	0.166
	StopNGo_LeisureTrip	0.697	2	0.705
	Congested_LeisureTrip	1.545	2	0.459
Age	StopNGo_RushTrip	0.017	2	0.992
	Congested__RushTrip	0.580	2	0.748
	StopNGo_LeisureTrip	0.994	2	0.601
	Congested_LeisureTrip	0.987	2	0.611

Table 5.20 presented the Chi Square of relationship between gender and age towards driver behavior. For all cases, the null hypothesis is accepted and a conclusion is made that there is no relationship between the demographic variables age and gender towards the behavior. When analyzing whether the presentation style has an effects on the driver decision, again, a chi square test was used. Figure 5.24 and Figure 5.25 depicted the results while Table 5.21 illustrates the Chi square figure. Our Null and alternative hypotheses are:

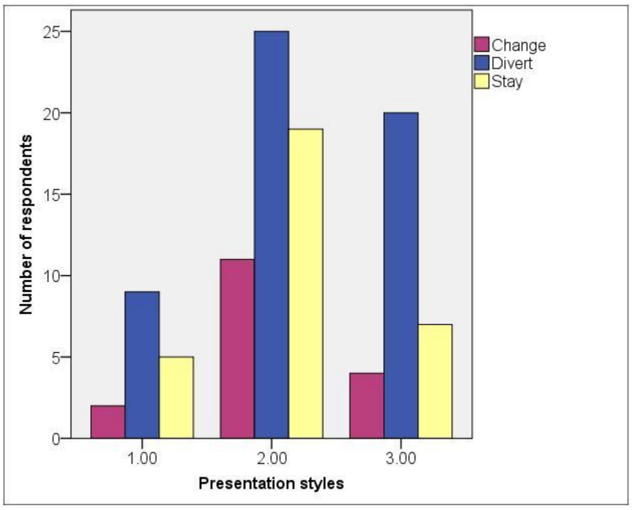
H_0: The behavior of the driver is not associated with traffic information presentation style
H_1: The behavior of the driver is associated with traffic information presentation style.



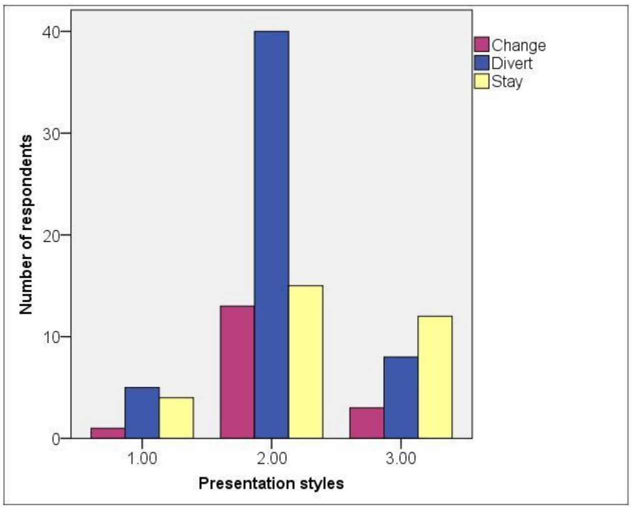
a) Stop and go (Familiar)



b) Stop and go (Not familiar)



c) Congested (Familiar)

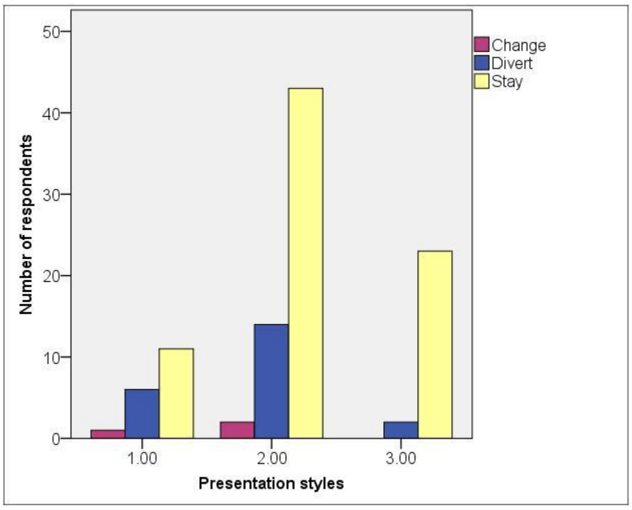


d) Congested (Not familiar)

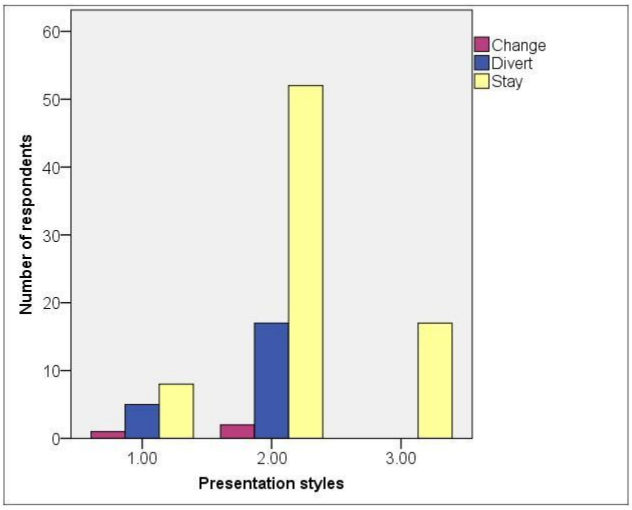
Legend: 1 Graphic, 2 Combination of graphic and 3 Text

Figure 5.24 Drivers' preferences on the information presentation style (Rush Trip)

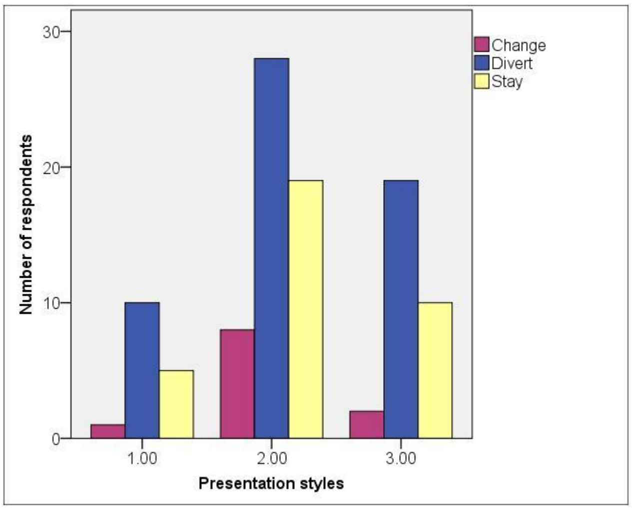
The results were analyzed using control effect which is the trip purpose (rush trip or leisure trip) with an alpha level of 0.05. In all cases, null hypothesis is accepted, since $p > 0.05$. A conclusion is made that the behavior of the driver is not associated with the presentation style of traffic information. Looking at the results of driver behavior once receiving the information, during rush trip and congested route, the drivers prefer to divert. The willingness to stay on the current route is much higher in leisure trip. Besides, comparing two different cases; having a rush trip or leisure trip, the willingness to stay on the current route is much higher in leisure trip.



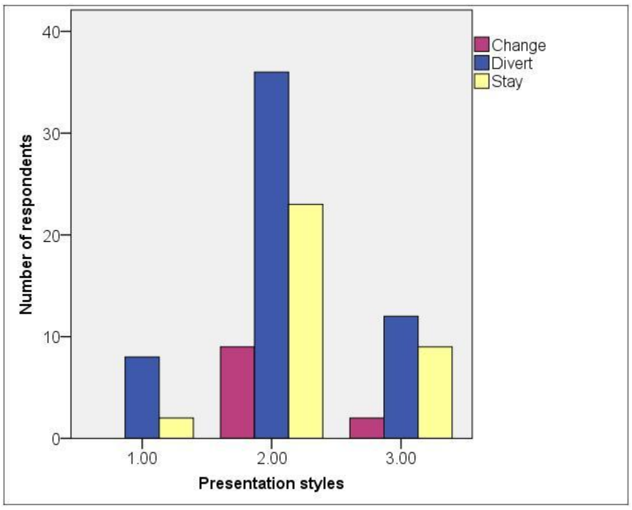
a) Stop and go (Familiar)



b) Stop and go (Not familiar)



c) Congested (Familiar)

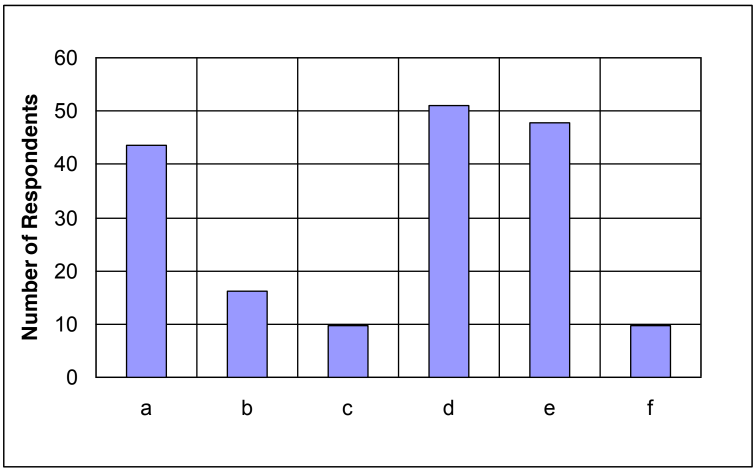


d) Congested (Not familiar)

Legend: 1 Graphic, 2 Combination of graphic and 3 Text
Figure 5.25 Drivers' preferences on the information presentation style (Leisure trip)

Table 5.21 Chi Square of relationship between presentation style and driver behavior

Cases	Cases	χ^2	Df	*p* value
Rush trip	Stop and Go (Familiar)	1.266	4	0.877
	Stop and Go (Not Familiar)	1.272	4	0.721
	Congested (Familiar)	3.135	4	0.529
	Congested (Not Familiar)	7.982	4	0.101
Leisure trip	Stop and Go (Familiar)	6.060	4	0.126
	Stop and Go (Not Familiar)	8.520	4	0.016
	Congested (Familiar)	2.153	4	0.694
	Congested (Not Familiar)	1.222	4	0.771



a. I am afraid that I will get lost if I deviate from my planned route
b. I do not feel safe driving in unfamiliar areas
c. I do not trust the information provided
d. I think it will be faster to stay on my current route
e. I do not think the alternative choices will be even faster((alternative route is provided)
f. Additional

Figure 5.26 Reasons for not adjusting the route

Looking at the reasons given by the drivers for not changing their route, Figure 5.26 depicted the results. The two main reasons of not adjusting the route are a) they think it will be faster to stay on the current route and b) they do not think the alternative choices will be any faster. Again, these results are consistent with Lee et al. (2004).

Chapter 6

Conclusions and Outlook

6.1. Conclusions

The main focus of this study was to determine the impact of traffic information presentation styles on driver behavior. An examination was made as to which traffic information presentation styles would be the most efficient for use in different driving scenarios. A stated preference survey was carried out for two case studies: in-vehicle and stationary devices. The study was also designed to investigate how drivers responded at different levels of traffic congestion. The main findings of this thesis can be described as answers to the following four research questions:

Question 1: Can a probe vehicle provide a reliable and sufficient amount of data containing travel time information?

As a starting point, the assumption that a probe vehicle could provide reliable and sufficient amount of data that could represent travel time information which then can be transferred and transformed into visual information in ArcGIS was examined. Tests were conducted in a simulated environment to ensure the accuracy of probe vehicle average travel time as compared to the 'true' link average travel time. Average travel times on links were tested. From Vissim microscopic simulation software, data sets consisting of individual vehicle travel times were obtained. The probe vehicle sample size was considered. The benchmark was, of course, 100% coverage of vehicles. However, only 10%, 20%, 30% and 40% of probe sample were specified, which in terms of number of vehicles were quite significant. The results relied on 'bootstrapping' techniques where this method of re-sampling represents the condition for probe vehicles. Results show that there is a strong correlation between the probe vehicles' travel time and the 'true' link travel time. This implies that the probe vehicles managed to accurately obtain information about travel time across a wide range of traffic volumes (situations). The results make it clear that computing travel time from probe vehicles under various traffic conditions is a reasonable method. Therefore, if only link travel times from probe vehicles can be obtained across the entire network, we could still utilize them as an indicator and report them in a more understandable way.

Question 2: Will presentation styles of traffic information influence driver's behavior?

Traffic information needs to be delivered to the driver in an understandable and widely accessible style. The way of presenting the information to the road user can support information comprehension and interpretation in a more effective way. A case study consisting of traffic information for in-vehicle devices as well as stationary devices was used. A stated preference (SP) survey was conducted in Munich to collect information regarding which traffic information presentation style is preferred by the drivers, and how their behavior is affected after receiving the information. The behavior that was investigated related to whether the driver stayed on the same route, changed transportation mode from car to public transport or vice versa or divert to an different route. A wide range of alternative styles of in-vehicle traffic information (namely text message, radio, map with building details, 'map with street only') in different driving scenarios ('stop and go' and congested) was presented.

Besides, graphic information, the combination of graphic and text as well as text on Variable message sign (VMS) panel was presented. The summary of the results is shown in Table 6.1.

Table 6. 1 Summary of the effect of the Presentation Style of Traffic Information, Age, and Gender towards Driver Behavior

Variables	Trip purpose	Traffic conditions	In-vehicle information	Stationary information
Presentation style			N	N
Age	Rush trip	Stop and Go	Y	Y
		Congested	N	N
	Leisure trip	Stop and Go	N	N
		Congested	N	N
Gender	Rush trip	Stop and Go	N	N
		Congested	N	N
	Leisure trip	Stop and Go	N	N
		Congested	N	N

The legends are described as follows:
Y: Have effect on driver behavior
N: Do not have effect on driver behavior

Chi Square analysis was used to find the relationship between presentation styles of traffic information, gender and age towards driver behavior. As listed in Table 6.1, in the case of in-vehicle information, the results show that the presentation style of traffic information does not play a significant role for influencing driver behavior. In the case of stationary information, the results also show that the presentation style of traffic information does not play a significant role for influencing driver behavior. Based on these findings, even though no relationship was found between presentation style and driver behavior, the level of complete customization of information is useful to ensure that the drivers are given information in an understandable format. If drivers are given information in a variety of presentation styles and formats, they then have to constantly adapt to being given information in a variety of styles. This can lead to driver confusion and frustration, especially when dealing with critical driving situations, such as being caught in traffic congestion because the driver does not understand the information presented to them. The other question that is addressed in the study is whether gender has an impact on behavior. It was hypothesized that women might act differently from men when dealing with a congested situation. The impact of age group of a person on behavior was also examined. When looking at the effects of demographic variables such as age and gender, only during rush trip with stop and go condition, age was found to have an effect on behavior. The results show that gender has no effect on driver behavior.

Question 3: How will the driver react to different presentation styles of traffic information while they are in different driving scenarios, from least to the most congested road?

In terms of driver behavior on what to do after receiving the information, only on a congested route do drivers prefer to divert. In addition, comparing two different cases (having a rush trip or leisure trip), the willingness to stay on the current route is much higher with a leisure trip. Thinking that it will be faster to stay on the current route and thinking the alternative choices will be slower are the main reasons why more drivers would rather choose to stay on their current route. Different behavioral patterns could be observed when drivers were confronted with more realistic situations. The observations demonstrate that drivers are more likely to divert their route only during a rush trip.

Question 4: Which presentation style will be the most efficient for the individual driving scenarios?

Table 6. 2 Summary of the most efficient presentation style of traffic information in different traffic conditions and purposes

		Presentation style of traffic information	
		In-vehicle information	Stationary information
Rush trip	Stop and go (Familiar)	Radio	Combination of graphic and text
	Stop and go (Not familiar)	Map with building	Combination of graphic and text
	Congested (Familiar)	Radio	Combination of graphic and text
	Congested (Not familiar)	Map with building	Combination of graphic and text
Leisure trip	Stop and go (Familiar)	Radio	Combination of graphic and text
	Stop and go (Not familiar)	Map with building	Combination of graphic and text
	Congested (Familiar)	Radio	Combination of graphic and text
	Congested (Not familiar)	Map with building	Combination of graphic and text

Three control variables of driver satisfaction in terms of understandability, usefulness and level of detail were analyzed using the Friedman test. Understandability refers to the ease with which people can understand the presented information; usefulness refers to how useful the information would be for a concerned task; and level of detail refers to the density of presented contents. These measurements had been applied to the case study of in-vehicle information as well as stationary information.

For in-vehicle information in relation to the preferred presentation style, maps with detailed buildings were ranked highest. The main reason for this preference is the presence of the buildings that provide additional orientation information. Using maps with detailed buildings, the driver can more easily map the route by themselves. Visual presentation of traffic information proves that color serves as eye catchers. The variable ‘understandability’ was significantly ranked as the best for Text SMS, Radio and Map with street (p= <.001) while the variable ‘level of detail’ was considered as the most favorable for ‘Map with buildings’.

For stationary information, as predicted, more drivers tend to choose ‘combination of graphic and text information’. However, the results based on the analysis do not demonstrate such a trend, when looking at different traffic scenarios. More drivers choose ‘combination of graphic and text information’ in ‘stop and go’ condition followed by ‘congested route’ and free flow regardless of route familiarity. When analyzing the results for the control variables, the ‘understandability’ variable was significantly ranked as the best for text information (p= <.001) while the variable ‘usefulness’ was considered as the most favorable for ‘combination of graphic and text’.

The analysis was carried out containing various trip variables, including the driver route familiarity and their travel purpose (rush or leisure trip). The actual observable traffic conditions such as level of congestion and variables pertaining to the information to which was being displayed was also carried out. It is assumed that drivers are influenced by these variables in making decisions whether to acquire and refer to traffic information in choosing their route. Theoretical understanding of the influence of information presentation styles on decision processes is still evolving, and some empirical findings are, as yet, difficult to account for with this approach. Some research explains the influence of traffic information presentation schemes using basic principles of perception. It seems inevitable that the subjective perceptions of drivers towards the effort of searching the information play a role. For example, although presenting a simple summary of traffic information may make it easier to understand, drivers may not find such traffic information credible and may be reluctant to use them. However, treating drivers’ decisions using a cognitive strategy as a variable that mediates the relation between decision aids and decision outcomes is a general approach that should prove to be useful. Combining fundamentals of cartography with traffic engineering is increasingly being seen as a solution that could free up resources. The approach in this study of using color for presenting traffic information served as ‘eye catchers’ that immediately direct attention to the road network. The transformation of the traffic data into visual presentation with the use of color to indicate severity of congestion enhances legibility. The color immediately makes clear that there is a deviation from a normal situation.

6.2. Outlook

The color coded network technique described in this study provides an idea of typical presentation style of information to gain insights of probe vehicle data sets. The technique allows users to get a visual overview of travel time variation. The approach which combined traffic simulation for travel time analysis and ArcGIS to provide visual information (a color coded network) can be easily implemented. Travel time accuracy can be assured when only only probe vehicles are used for travel time measurement. From the results of this study, further studies can be conducted to test whether drivers fully understand the meaning of every detail of the information provided. Further advancement to improve the current situation can be made. It is good to know that many drivers choose to stay on their route, where one could consider this as a good indicator on the alternative information such as waiting time. This option however not only focuses on the best route with minimum travel time, but also routes with minimum cost. Besides, more samples with many alternative ways of each presentation style of traffic information would also be recommended for the future.

A consideration to develop and apply advanced presentation styles of traffic information techniques can also be considered. Instead of simply color-coding classified data, analytical visualization tools based on techniques such as 3D color surface with a z-axis representing the speed, dynamic linking and brushing etc. can be developed and tested with user participation.

In this study, a questionnaire survey was selected as it is an effective method of data collection in hypothetical situations and is cheaper than other methods such as traffic simulators. Many researchers have reported useful results for fundamental characteristics of choices behavior performed by stated preference (SP) survey. The study design of using SP on the internet does not really offer experience in assimilating ATIS, since the internet time to view the information and assimilate it does not match the driving experience. However, it allowed responses to traffic information to be tested in a cost effective manner. Some of the presentation styles used in this study are hypothetical and do not yet exist. Therefore, future research can be conducted using the existing presentation styles of traffic information.

It is not easy to obtain accurate data, in fact, good accurate data often needs to be planned. For manipulating probe vehicle data, although this study is based on simulation, once proven successful by further testing and evaluation, it can be a help for long-term savings in system operation and maintenance. The simulation data in the study has provided a clear view as to how travel times are temporarily correlated. The approach for calculating the travel time on network links is a simple one and can be easily used. The scheme proved that travel time can be accurately measured using probe vehicles alone. One underlying assumption in our study in terms of potential future field applications is that the variation in probe vehicle data accuracy involved is not too high. Many further theoretical developments are possible with the model, such as using statistical techniques to smooth the probe vehicle data, using traffic flow theory based concepts for finding the averaging parameter that might effects the accuracy of the transmitted of the data such as the turning movement. The results with the very simple scheme of using the simulation approach itself yield good numbers and thus the method is useful from a purely practical viewpoint. The problem is that the micro simulation of traffic is a relatively new way of modeling. Very often it happens that some models do not model certain traffic behavior properly. Therefore, it would be useful to calibrate the model to provide potentially better results and match real-world conditions more accurately. Future research is needed on this issue to further explore the relationship between the probe percentage and the prediction error.

Bibliography

Abdel-Aty, M., and Abdalla, F. "Simulation experiments to investigate drivers adherence with traffic information." *Intelligent Transportation Systems, 2005. Proceedings. 2005 IEEE*, 22-27.

Adler, J. L., and Blue, V. J. (1998). "Toward the design of intelligent traveler information systems." *Transportation Research Part C: Emerging Technologies*, 6(3), 157-172.

Akamatsu, M., yoshioka, M., Imacho, N., Daimon, T., and Kawashima, H. (1997). "Analysis of Driving a Car With a Navigation System in an Urban Area." Ergonomics and Safety of Intelligent Driver Interfaces (Human Factors in Transportation), Y. I. Noy, ed., Lawrence Erlbaum Assoc Inc 85-96.

Allen, R. W., Ziedman, D., Torres, J. F., Halati, A., Rosenthal, T. J., and Stein, A. C. (1991). "A Human Factors Study of Driver Reaction to In-Vehicle Navigation Systems." Future Transportation Technology Conference & Exposition, , Portland, OR, USA.

Anderson, J., and Bell, M. "Travel time estimation in urban road networks." *Intelligent Transportation System, 1997. ITSC '97., IEEE Conference on*, 924-929.

Anttila, V., and Luoma, J. (2005). "Surrogate in-vehicle information systems and driver behaviour in an urban environment: A field study on the effects of visual and cognitive load." *Transportation Research Part F: Traffic Psychology and Behaviour*, 8(2), 121-133.

Ashish, S., Piyushimita, T., Xia-Quon, Z., and Alan, K. (1997). "Frequency of Probe Reports and Variance of Travel Time Estimates." *Journal of Transportation Engineering*, 123(4), 290-297.

Barfield, W., and Dingus, T. A. (1998). *Human Factors in Intelligent Transportation Systems*, Lawrence Erlbaum Associates, Mahwah, NJ.

Ben-Elia, E., Erev, I., and Shiftan, Y. (2008). "The combined effect of information and experience on drivers' route-choice behavior." *Springer Journal of the Transportation* 35(2 (March)), 165-177.

Benson, B. G. (1996). "Motorist Attitudes About Content of Variable-Message Signs." *Journal Transportation Research Record: Journal of the Transportation Research Board*, 1550, 48-57.

Bierlaire, M., Thémans, M., and Axhausen, K. (2006). "Analysis of driver's response to real-time information in Switzerland." *European Transport* (34), 21-41.

Brookhuis, K. A., and Dicke, M. (2009). "The effects of travel information presentation through nomadic systems on driver behaviour " *European Transport Research Review*.

Brundell-Freij, K. "Sampling, spceification and estimation as sources of inaccuracy in complex transport models-some examples analyzed by Monte Carlo simulation and bootstrap." *European Transport Conference*, Cambridge, England, 225-237.

Brunner, D., Cross, G., McGhee, C., Levis, J., and Whitney, D. "Toward increased use of simulation in transportation." *Simulation Conference Proceedings, 1998. Winter*, 1169-1175 vol.2.

Byon, Y.-J., Shalaby, A., and Abdulhai, B. (2006). "GISTT: GPS-GIS Integrated System for Travel Time Surveys." *TRB 2006 annual meeting CD-ROM paper number 1555*.

Campbell, J. L., Carney, C., and Kantowitz, B. H. (1998). "Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) And Commercial Vehicle Operations (CVO)." US Department of Transport (Federal Highway Administration).

Chatterjee, K., Hounsell, N. B., Firmin, P. E., and Bonsall, P. W. (2002). "Driver response to variable message sign information in London." *Transportation Research Part C: Emerging Technologies*, 10(2), 149-169.

Chen, M., and Chien, S. I. J. (2000). "Determining the Number of Probe Vehicles for Freeway Travel Time Estimation Using Microscopic Simulation." *Transportation Research Board, Washington, DC,* , pp.61-68.

Chen, S., Ray, C., Tan, J., and Claramunt, C. "Analysis of an Integrated Transportation GIS for the City of Guangzhou, China." *ITS Telecommunications Proceedings, 6th International Conference on*, Chengdu 894 - 897

Cheu, R. L., Xie, C., and Lee, D.-H. (2002). "Probe Vehicle Population and Sample Size for Arterial Speed Estimation." *Computer–Aided Civil and Infrastructure Engineering,* Volume 17(Number 1), pp. 53-60(8).

Choocharukul, K. (2008). "Effects of Attitudes and Socioeconomic and Travel Characteristics on Stated Route Diversion: Structural Equation Modeling Approach of Road Users in Bangkok, Thailand." *Journal Transportation Research Record: Journal of the Transportation Research Board*, 2048, 35-42.

Claramunt, C., Jiang, B., and Bargiela, A. (2000). "A new framework for the integration, analysis and visualisation of urban traffic data within geographic information systems." *Transportation Research Part C: Emerging Technologies*, 8(1-6), 167-184.

Cohen, S., Bosseboeuf, J. L., and Schwab, N. "Probe vehicle sample sizes for travel time estimation on equipped motorways." *Road Transport Information and Control, 2002. Eleventh International Conference on (Conf. Publ. No. 486)*, 172-176.

D'Este, G. M., Zito, R., and Taylor, M. A. P. (1999). "Using GPS to Measure Traffic System Performance." *Journal of Computer- Aided Civil and Infrastructure Engineering*, Vol. 14, 273-283.

Dia, H. (2002). "An agent-based approach to modelling driver route choice behaviour under the influence of real-time information." *Transportation Research Part C: Emerging Technologies*, 10(5-6), 331-349.

Dia, H., and Panwai, S. (2007). "Modelling drivers' compliance and route choice behaviour in response to travel information." *Journal of Nonlinear Dynamics*, 493-509.

Dicke-Ogenia, M., Coffeng, G., and Brookhuis, K. A. "Improved access to cities through travel information a full colour information panel." *European Transport Conference* Leeuwenhorst Conference Center, The Netherlands.

Dingus, T. A., Hulse, M. C., Mollenhauer, M. A., Fleischman, R. N., McGehee, D. V., and Manakkal, N. (1997). "Effects of Age, System Experience, and Navigation Technique on Driving with an Advanced Traveler Information System " *Human Factors: The Journal of the Human Factors and Ergonomics Society*, Volume 39(Number 2), 177-199.

Druitt, S. (2000). "Paramics article: An introduction to Paramics."

El-Geneidy, A. M., and Bertini, R. L. "Toward validation of freeway loop detector speed measurements using transit probe data." *Intelligent Transportation Systems, 2004. Proceedings. The 7th International IEEE Conference on*, 779-784.

Erke, A., Sagberg, F., and Hagman, R. (2007). "Effects of route guidance variable message signs (VMS) on driver behaviour." *Transportation Research Part F: Traffic Psychology and Behaviour*, 10(6), 447-457.

Feng, C. M., and Kuo, Y. W. (2007). "Modeling Drivers' Stated En Route Switching Behavior Under Various Information Scenarios." *Journal of the Eastern Asia Society for Transportation Studies*, Volume 7.

Ferman, M. A., Blumenfeld, D. E., and Xiaowen, D. "A simple analytical model of a probe-based traffic information system." *Intelligent Transportation Systems, 2003. Proceedings. 2003 IEEE*, 263-268 vol.1.

Fi, I., Barsi, A., Lovas, T., Siki, Z., and Fordos, G. "Real-time flow data analysis by GIS: Internet and WAP approach." *Intelligent Transportation Systems, 2005. Proceedings. 2005 IEEE*, 989-993.

Gan, H., Sun, L., Chen, J., and Yuan, W. (2006). "Advanced Traveler Information System for Metropolitan Expressways in Shanghai, China." *Journal Transportation Research Record: Journal of the Transportation Research Board*, 2006(1944), 35-40.

Gan, H. (2010). "Graphical route information panel for the urban freeway network in Shanghai, China." *IET Intelligent Transport Systems*, 4(3), 212-220.

Garrick, N. W., Miniutti, P., Westa, M., Luo, J., and Bishop, M. (2005). "Effective Visualization Techniques for the Public Presentation of Transportation Projects." University of Connecticut, Connecticut Transportation Institute, Storrs, CT 06269-5202.

Goldsberry, K. "Limitations and potentials of real-time traffic visualization for wayfinding." *22nd ICA/ACI International Cartographic Conference*, Coruna,Spain.

Gravetter, F. J., and Wallnau, L. B. (2009). *Statistics for the Behavioral Sciences, International Edition*, Cengage Learning Services.

Grol, H. J. M. v., Danech-pajouh, M., Manfredi, S., and Whittaker, J. "DACCORD: on-line travel time prediction." *World Conference on Transport Research Society (WCTRS)*, 455-467.

Hamish Jamson, A., and Merat, N. (2005). "Surrogate in-vehicle information systems and driver behaviour: Effects of visual and cognitive load in simulated rural driving." *Transportation Research Part F: Traffic Psychology and Behaviour*, 8(2), 79-96.

Harms, I. M., Dicke1, M., and Brookhuis, K. A. (2005). "Different congestion indications on dynamic route information displays." Human Factors in Design, Safety, and Management K. A. B. D. de Waard, R. van Egmond, and Th. Boersema, ed., Shaker Publishing, 73 - 80.

Hartman, D., and Herout , P. (2005). "Head Leading Algorithm and GIS data analysis in simulation of traffic in Pilsen." *International Journal of Simulation Systems, Science and Technology, Nottingham Trend University*.

Hato, E., Taniguchi, M., Sugie, Y., Kuwahara, M., and Morita, H. (1999). "Incorporating an information acquisition process into a route choice model with multiple information sources." *Transportation Research Part C: Emerging Technologies*, 7(2-3), 109-129.

Hoekstra, E., Williams, M., Green, P., and Paelke, G. (1992). "Usability of text, graphic, and video in-car traffic information for diversion decisions." University of Michigan, Ann Arbor, Transportation Research Institute.

Hughes, R. G. (2004). "Visualization in Transportation: Current Practice and Future Directions " *Journal of the Transportation Research Board*, 1899 167-174.

Inokuchi, H., Kawakami, S., and Ogino, H. "Development of a real-time traffic simulation model using traffic survey data." *10th World Congress and Exhibition on Intelligent Transport Systems* Madrid, Spain.

Ishizaka, T., A.Fukuda, and S.Narupiti. (2005). "Evaluation of probe vehicle system using micro simulation model and cost analysis." *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 6, 2502 - 2514.

Jan, O., Horowitz, A. J., and Peng, Z.-R. (2000). "Using GPS Data to Understand Variations in Path Choice." *Transportation Research Record 1725, TRB*, 37-44.

Jou, R.-C. (2001). "Modeling the impact of pre-trip information on commuter departure time and route choice." *Transportation Research Part B: Methodological*, 35(10), 887-902.

Jou, R.-C., Lam, S.-H., Liu, Y.-H., and Chen, K.-H. (2005). "Route switching behavior on freeways with the provision of different types of real-time traffic information." *Transportation Research Part A: Policy and Practice*, 39(5), 445-461.

Ka-hung, L., and Wing-gun, W. (2000b). "SP Approach toward Driver Comprehension of Message Formats on VMS." ASCE, 221-227.

Khattak, A. J., Targa, F., and Yim, Y. (2003). "Investigation of Traveler Information and Related Travel Behavior in the San Francisco Bay Area." California Partners for Advanced Transit and Highways (PATH).

Klein, L. A. (2001). *Sensor Technologies and Data Requirements for ITS Applications*, Artech House Publishers

Kloot, G. "Melbourne's Arterial Travel Time System." *The 6th World Congress on ITS*, Toronto, Canada.

Kolbl, R., McDonald, M., Fisher, G., and Brackstone, M. "Probe vehicle: a comparison of motorway performance measure with other motorway flow detection techniques." *Road Transport Information and Control, 2002. Eleventh International Conference on (Conf. Publ. No. 486)*, 182-186.

Kong, Q.-j., Chen, Y., and Liu, Y. "An Improved Evidential Fusion Approach for Real-time Urban Link Speed Estimation." *IEEE Intelligent Transportation Systems Conference* Seattle, Washington, USA, , 562-567.

Konig, R., Saffran, A., and Breckle, H. "Modelling of drivers' behaviour." *Vehicle Navigation and Information Systems Conference, 1994. Proceedings., 1994*, 371-376.

Koppelman, F. S., Schofer, J. L., Bhandari, N., Sethi, V., and Ivan, J. N. (1994). "Calibration of probe and fixed detector algorithm parameters with simulated data" ADVANCE Project Technical Report TRF-ID-151."

Lai, K.-H., and Wong, W.-G. "The Influence of Traffic Information Presentation Format on Driver Behaviour." *The Third Conference of the Hong Kong Society for Transportation Studies*, Hong Kong, 353-358.

Lappin, J. (2000). "Advanced Traveler Information Service (ATIS): What do ATIS Customers Want?" U.S. Department of Transportation.

Lavalette, B. C. d., Tijus, C., Poitrenaud, S., and Leproux, C. "Road Travel Time Information on VMS and Traffic Congestion." *Proceedings of the Third International Conference on Wireless and Mobile Communications*

Lee, C., Choi, K., and Lee, S. (2004). "Evaluation of Drivers' Responses to ATIS: A Practical VMS Based Analysis." *KSCE Journal of Civil Engineering*, Vol. 8(2), 233-237.

Lim, C., Sayed, T., and Navin, F. (2004). "A driver visual attention model. Part 1. Conceptual framework " *Canadian Journal of Civil Engineering*, Volume 31(Issue 3), 463-472.

Lin, H.-e. (2004). "The application of micro-simulation in the development of dynamic travel time prediction model." 26th Conference Of Australian Institutes of Transport Research, Australia.

Linnartz, J. P. M. G., and Westerman, M. "Monitoring a metropolitan freeway system using probe vehicles and random access radio channel." *Vehicular Technology Conference, 1994 IEEE 44th*, 410-414 vol.1.

Liu, H. X., He, X., and Recker, W. (2007). "Estimation of the time-dependency of values of travel time and its reliability from loop detector data." *Transportation Research Part B: Methodological*, 41(4), 448–461.

Liu, Y.-c. (2000). "Effect of advanced traveler information system displays on younger and older drivers' performance." *Displays*, 21(4), 161-168.

Lohse, G. L. (1997). "The role of working memory on graphical information processing." Taylor & Francis, 297 - 308.

Lotan, T. (1997). "Effects of familiarity on route choice behavior in the presence of information." *Transportation Research Part C: Emerging Technology*, 5(3-4), 225-243.

Louviere, J. J., Hensher, D. A., D.Swait, J., and Adamowicz, W. (2000). *Stated Choice Methods: Analysis and Applications*, Cambridge University Press

Lu, C.-T., Boedihardjo, A. P., and Zheng, J. "AITVS: Advanced Interactive Traffic Visualization System." *22nd International Conference on Data Engineering* 167- 168.

MacEachren, A. M. (2004). *How Maps Work: Representation, Visualization, and Design*, The Guilford Press; .

Mannering, F., Kim, S.-G., Ng, L., and Barfield, W. (1995). "Travelers' preferences for in-vehicle information systems: An exploratory analysis." *Transportation Research Part C: Emerging Technologies*, 3(6), 339-351.

Muizelaar, T. J., and Arem, B. v. (2008). "Drivers' Preferences for Traffic Information for Nonrecurrent Traffic Situations." *Transportation Research Record: Journal of the Transportation Research Board*, 2018 /(2007), 72-79.

Ng, L., Barfield, w., and Spyridakis, J. H. (1998). "Survey methodologies for defining user information requirements." Human Factors in Intelligent Transportation Systems, W. barfield and T. A. Dingus, eds., Lawrence Erlbaum and Associates, London, 458.

Okamoto, H. "Recent developments in Japanese traffic information supply system." *Vehicle Navigation and Information Systems Conference, 1993., Proceedings of the IEEE-IEE*, 204-207.

Okutani, I., and Stephanedes, J. (1984). "Dynamic prediction of traffic volume through kalman filter theory." *Transport Research Part B*, Vol. 18B, 1-11.

Pack, M. L. (2010). "Visualization in Transportation: Challenges and Opportunities for Everyone." *Computer Graphics and Applications, IEEE*, 30(4), 90-96.

Ortúzar, J. d. D., and Willumsen, L. G. (2001). *Modelling Transport* John Wiley & Sons Inc.

Pauzie, A., and Marin-Lamellet, C. "Analysis of aging drivers' behaviors navigating with in-vehicle visual display systems." *Vehicle Navigation and Information Systems Conference, 1989. Conference Record*, 61-67.

Peeta, S., and Ramos, J. L. (2006). "Driver response to variable message signs-based traffic information." *Intelligent Transport Systems, IEE Proceedings*, 153(1), 2-10.

Peeta, S., Ramos, J. L., and Pasupathy, R. (2000). "Content of Variable Message Signs and On-Line Driver Behavior." *Transportation Research Record: Journal of the Transportation Research Board*, 1725 102-108.

Pursula, M. (1999). "Simulation of Traffic Systems - An Overview." *Journal of Geographic Information and Decision Analysis*, vol.3(no.1), pp. 1-8.

Rao, K. M. L., Sunitha, K., and Jayasree, K. "Dynamic geographic information system for intelligent traffic guidance systems." *Geoscience and Remote Sensing Symposium, 2005. IGARSS '05. Proceedings. 2005 IEEE International*, 4 pp.

Richards, A., and McDonald, M. (2007). "Questionnaire surveys to evaluate user response to variable message signs in an urban network." *Intelligent Transport Systems, IET*, 1(3), 177-185.

Richards, A., McDonald, M., Fisher, G., and Brackstone, M. (2005). "Investigation of driver comprehension of traffic information on graphical congestion display panels using a driving simulator." *European Journal of Transport and Infrastructure Research*, 4(4), 417-435.

Richardson, A. J., Ampt, E., and Meyburg, A. (1995). *Survey methods for transport planning*, Eucalyptus Press, University of Melbourne, Australia

Rilett, L. R., D.Park, and B.Gajewski. "Estimating confidence interval for freeway corridor travel time forecasts." *6th World Congress on Intelligent Transport Systems*, Toronto, Canada.

Ross, T., and Burnett, G. (2001). "Evaluating the human-machine interface to vehicle navigation systems as an example of ubiquitous computing." *International Journal of Human-Computer Studies*, 55(4), 661-674.

Schönfeld, G., Reischl, A., and Tsavachidis, M. "Dynamic Driver Information Goes Graphical – A New Quality in Urban Traffic Information." *7th World Congress on Intelligent Transport System*, Torin, Italy.

Sisiopiku, V., and Rouphail, N. (1994). "Toward the Use of Detector Output for Arterial Link Travel Time Estimation." *Transportation Research Record 1457 (TRB), Washington, D.C.*, pp. 158-166.

Taylor, M., Young, W., and Bonsall, P. W. (2000). *Understanding traffic systems*, Gower Publishing Co., England.

Taylor, M. A. P., Woolley, J. E., and Zito, R. (2002). "Integration of the global positioning system and geographical information systems for traffic congestion studies." *Transportation Research Part C: Emerging Technologies*, 8(1-6), 257-285.

Thomas, K., and Dia, H. F. (2004). "Simulation of lane-blocking incidents and probe vehicle data for development of automated arterial incident detection models." Workshop on Traffic Simulation, Bridging Theory and Practice. , Brisbane, Australia.

Tong, D., Merry, C. J., and Coifman, B. (2005). "Traffic Information Deriving Using GPS Probe Vehicle Data Integrated with GIS." Department of Civil and Environmental Engineering and Geodetic science, The Ohio State University, Ohio.

Toppen, A., and Wunderlich, K. (2003). "Travel time data collection for measurement of Advanced Traveller Information System accuracy." Federal Highway Administration.

Turner, S. M., Eisle, W. L., Benz, R. J., and Holdener, D. J. (1998). *Travel Time Data Collection Handbook*, Texas Transportation Institute, Texas.

Turner, S. M., and Holdener, D. J. "Probe vehicle sample sizes for real-time information: the Houston experience." *Vehicle Navigation and Information Systems Conference, 1995. Proceedings. In conjunction with the Pacific Rim TransTech Conference. 6th International VNIS. 'A Ride into the Future'*, 3-10.

Uchida, T., Iida, Y., and Nakahara, M. "Panel survey on drivers' route choice behavior under travel time information." *Vehicle Navigation and Information Systems Conference, 1994. Proceedings., 1994*, 383-388.

Wang, J.-H., and Cao, Y. (2005). " Assessing Message Display Formats of Portable Variable Message Signs." *Journal Transportation Research Record: Journal of the Transportation Research Board*, 2005(1937), 113-119.

Wang, J.-H., Hesar, S. G., and Collyer, C. E. (2007). "Adding Graphics to Dynamic Message Sign Messages." *Transportation Research Record: Journal of the Transportation Research Board*(Volume 2018), 63-71.

Wardman, M., Bonsall, P. W., and Shires, J. D. (1997). "Driver response to variable message signs: a stated preference investigation." *Transportation Research Part C: Emerging Technologies*, 5(6), 389-405.

Wickens, C. D. (1984). "Processing Resources in Attention." in Varieties of Attention, Academic Press, New York 63-102.

Yanying, L., and McDonald, M. "Link travel time estimation using single GPS equipped probe vehicle." *Intelligent Transportation Systems, 2002. Proceedings. The IEEE 5th International Conference on*, 932-937.

Zhang, L., and Levinson, D. (2008). "Determinants of Route Choice and Value of Traveler Information: A Field Experiment." *Transportation Research Record: Journal of the Transportation Research Board*, 2086(2007), 81-92.

Zhou, M., Korhonen, A., Malmi, L., Kosonen, L., and Luttinen, T. (2006). "Integration of Geographic Information System for Transportation with Real-Time Traffic Simulation System: Application Framework Framework." *Journal Transportation Research Record: Journal of the Transportation Research Board*, 2006(1972), 78-84.

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Abbreviations

ATIS	Advanced Traveler Information Systems
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
CMS	Changeable Message Signs
DAB	Digital Audio Broadcasting
DMS	Dynamic Message Signs
EMS	Electronic Message Signs
ITGS	Intelligent Traffic Guidance and Monitoring System
ITS	Intelligent transport system
GPS	Global Positioning System
GIS	Geographical Information System
GIS-T	Geographic Information System for Transportation
OD	Origin-Destination
PTV	Planung Transport Verkehr
RTIA	Real-Time Traffic Information Applications
RTSS	Real-Time Traffic Simulation Systems
MMOGs	Multiplayer On-line Games
TMC	Traffic Management Center
VISC	Vehicle Information and Communication System
VMS	Variable Message Signs

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