DECISION SUPPORT SYSTEM FOR LOCATING TRAFFIC INFORMATION
DISSEMINATION SITES ALONG FREEWAY CORRIDORS

by

Christopher Nutakor

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APPROVED:

Antoine G. Hobeika, Ph.D., Chairman

Robert Schulman, Ph.D.

Antonio A. Trani, Ph.D.

R. Sivanandan, Ph.D.

Richard Greene, Ph.D.

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Christopher K. Nutakor
Antoine G. Hobeika, Ph.D., Chairman
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(ABSTRACT)

Dynamic route guidance systems which are products of the Intelligent Transportation Systems (ITS) Technology have been reasonably useful in guiding motorists from their origins to destinations. In general, transportation networks could be used more efficiently if dynamic route guidance information could be provided to motorists at all relevant locations along freeway corridors. This is however not possible, particularly because of financial constraints. It is therefore imperative that information be provided to motorists at locations where it will be of maximum benefit.

The objective of this research is to develop methodologies and computer models for estimating utility of motorist information at different locations along freeway corridors. Such models will be very useful in guiding transportation professionals to optimize resources when providing guidance information to motorists.
The methodologies have been developed based on both recurrent and non recurrent traffic congestion situations. The methodologies assume that motorists behave rationally and will divert from congested freeways to uncongested arterials based on the user equilibrium traffic assignment criteria. The utility of information estimation has however been based on total system time savings. Computer models have been developed based on the methodologies using the C++ programming language. Nonetheless, because the computer models have been developed based on historical traffic data, they have been validated using real time simulation models developed with the SIMSCRIPT II.5 programming language. The validation process proved reasonably successful.

Many factors which include traffic volumes on alternate arterial routes to a given freeway link, the number of alternate routes to the freeway link especially under recurrent traffic congestion conditions, link lengths, volume of traffic on the freeway link and incident history in the case of non recurrent congestions influence the utility of information. With the particular networks investigated in this research however, the results indicate volume of traffic on the freeway links as the most influencing factor, since freeway links with relatively high traffic volumes tend to have relatively high utility values. The reason for this is probably because of the small size nature of the networks used, hence as a result all the freeway links tend to have only one or two alternate routes and the traffic volumes on the arterial links also do not differ significantly. The freeway link volumes therefore become the dominating factor in influencing the information utilities.
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CHAPTER I
INTRODUCTION

1.1 Background

Traffic congestion is the primary transportation problem which currently confronts almost all the world’s cities. Costs of congestion which are measured in lost productivity, increased fuel use and environmental pollution are increasing with increasing traffic volumes on the roads. Congestion also strains the resources of cities and national governments as they struggle to provide the transportation infrastructure demanded by road users. The cost of congestion in the United States has been estimated as $100 billion per year and congestion related accidents also drain away another $70 billion per year. It has been documented that 54 percent of peak hour travel on urban interstates occurred under congested conditions in 1983. This figure increased to 61 percent in 1985 and to 65 percent in 1987. Also urban travel increased by 9.4 percent between 1985 and 1987 (FHWA 1989). Traffic volumes on America’s highway network have been predicted to double from 1.9 trillion vehicle miles of travel (VMT) in 1988 to 3.8 trillion VMT in 2020 with probable increase in congestion (US DOT 1989). Figure 1.1 provides some statistics of present and future projections of traffic congestion effects on freeways in the United States.
Figure 1.1 Total delay due to freeway congestion in the United States
1.1.1 Causes of Congestion

There are two main components of traffic congestion. These are Recurrent and Non-recurrent traffic congestions which have been illustrated in Figure 1.2.

Recurrent Congestion

Recurrent Congestion typically occurs every day during peak periods due to demand exceeding the capacity of a section of highway. This congestion often results from traffic moving between work and home during "rush" hours. Transportation system management strategies are used to mitigate recurrent congestion.

Non-Recurrent Congestion

Non-recurrent congestion occurs due to an incident or other event which blocks freeway lanes or otherwise reduces capacity. These incidents or events include accidents, disabled vehicles and construction or maintenance activities. It is estimated that non-recurrent congestion accounts for over 60% of urban freeway congestion in the US Incident management strategies are used to mitigate non-recurrent congestion.

Incidents which are predominantly in the form of roadway crashes are considered to be due to three main components of the highway system; the driver, the road environment and the vehicle. In the 1970s, two major studies, one in the US and one in the UK, were
performed to identify factors associated with a large sample of crashes. The US study was performed by Indiana University. The study has been described in many reports such as Treat (1980). The British study was performed by the Transport and Road Research Laboratory, and described by Sabey and Taylor (1980). In both studies, a team of multidisciplinary experts conducted a detailed post crash examination of crashes satisfying specified selection criteria. The crash sites were examined for physical evidence, the vehicles involved were examined by an engineer, and the participants involved in the crash were interviewed in depth. Based on this information, factors contributing to the crashes were identified. Rumar (1985), graphically summarized the results from both studies as shown in Figure 1.3.

Although the studies were performed independently, the results are remarkably consistent. Each study reveals that when only one factor is identified, it is overwhelmingly the road user (65% in the British study and 57% in the US study). The British study finds that road user factors are present as sole or contributory factors in 94% of the crashes, the US study 93%. Consequently, there is only about 6% of crashes not linked in anyway to the road user.
Figure 1.2 Causes of urban congestion
Figure 1.3 Contributing factors to incidents
1.1.2 Promising Solutions to Traffic Congestion

Several efforts by transportation professionals over the years to mitigate the traffic congestion problems could not yield satisfactory results. The failure of the traditional congestion problem solving tools (transportation system management strategies) to remedy the traffic congestion problems has resulted in the evolution of a new technology which has been made possible by developments in computers and communication systems. Transportation Professionals believe that, this new technology known as Intelligent Transportation Systems (ITS) is capable of sufficiently reducing the congestion problem, if not to eradicate it completely. The ITS technology consists of four main components, namely: Advanced Traffic management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Commercial Vehicle Operations (CVO), Advanced Public Transportation Systems (APTS) and Advanced Vehicle Control Systems (AVCS) (*IVHS America 1992*).

ATMS will integrate management of various roadway functions, including freeway ramp metering and arterial signal control. It will predict traffic congestion and provide alternative routing instructions to vehicles over wide areas, in order to maximize the efficiency of use of the highway network. ATIS provides a variety of information that assists travelers in reaching a desired destination via private vehicle, public transportation, or a combination of the two. The information will include optimal routes, recommended speeds etc. AVCS enhances the driver’s control of the vehicle to make travel safer and more efficient by provision of collision avoidance systems, automatic braking and steering away from collisions etc. APTS will use constituent technologies of
ATMS, ATIS and AVCS to improve operation of high occupancy vehicles, including transit buses, car and vanpools.

There is currently a significant amount of research going on with each of the components of ITS, especially in ATMS and ATIS. The state-of-the-art ATIS and ATMS models show very promising results, especially in motorist travel time savings.

1.2 Problem Statement

There has been rapid growth and developments in the ITS technology since its inception in the mid-1980’s. Countries like Germany, Japan, Great Britain and the United States have been contributing significant resources towards research in this area. In the United States, the ITS technology, especially in the areas of ITS and ATMS has undergone a remarkable growth since the passage of the Intermodal Surface Transportation Efficiency Act of 1992 (ISTEA).

The ATIS and ATMS technologies are being used widely in the United States to dynamically guide motorists from their origins to their destinations. The ability to use ATMS to predict traffic congestion enables the transmission of real time information on traffic conditions to motorists. The traffic congestion parameters are also used to provide alternative routing instructions to vehicles over wide areas, in order to minimize travel times. ATIS, without using any support from outside the vehicle can employ visual and auditory presentations to inform drivers of their current locations, aid them in planning their routes and also provide other informational services. In another form ITS may be integrated with ATMS by providing communication between the vehicle and ATMS that
provides continuous information to the driver regarding traffic conditions, roadway congestion and alternate routes. The success of dynamic route guidance in alleviating traffic congestion depends primarily among other things on the effectiveness of the communication devices that link the system components together.

The provision of route guidance information to motorists using ATMS or integrated ATMS/ATIS can be achieved through the use of Changeable Message Signs (CMS), beacons etc. While the best results from dynamic route guidance information could be obtained by providing information to motorists at every location on the network and at all times, this is not possible in the face of limited economic resources. It is therefore imperative that information be provided to motorists at locations where it will be of maximum benefit. Nevertheless, the fact that traffic information to motorists is most useful during traffic congestion situations implies that any research to identify locations of high information utility should be linked to traffic congestion. Thus understanding of the two main sources of traffic congestion which are recurrent and non-recurrent congestions is germane to the development of any methodology for finding locations of high information values. Peak period travel demand patterns which are the main causes of recurrent congestion and roadway sections with high potentials of incident occurrence deserve in-depth study in establishing any such methodology.

The intent of this research has been to develop a methodology and a model for estimating information utility at potential information locations on freeways in a traffic network. Such knowledge will ensure a more effective distribution of resources and significant cost savings. The cardinal objectives of the research have been outlined in the following section.
1.3 Research Objectives

This research has established a general and systematic criteria for estimating the utility of traffic information along freeway corridors. For the purposes of the research, the focus has essentially been on practical freeway sections such as freeway to freeway interchanges and potential diversion exits.

As mentioned earlier, traffic information is most useful to motorists during traffic congestion situations. Therefore the research has the goal of developing a utility function based on the two major causes of traffic congestion: Recurrent traffic congestion and Non-recurrent traffic congestion.

The research goal has been attained by undertaking the following objectives:

- Development of a methodology and a computer based model for estimating the utility of travel time information to motorists under recurrent traffic congestion conditions.
- Development of a methodology and a computer based model for estimating the utility of travel time information to motorists under non recurrent traffic congestion conditions.
- Integration of the recurrent and non recurrent congestion based computer models
- Validation of the computer models using simulation methods
1.4 Organization of the Research

The remainder of the research is organized as follows: Chapter 2 presents the literature review on infrastructure based dynamic route guidance systems, in-vehicle based dynamic route guidance systems and methods for evaluating benefits of route guidance systems. Chapter 3 gives the formulation of the research problem as it pertains to this work. Chapter 4 describes the development of the computer model which is the main product of this research. Chapter 5 also describes a simulation approach that was adopted to validate the computer model described in Chapter 4. Finally, Chapter 6 concludes the research by describing the major findings and further research relevant to this work.
CHAPTER II
LITERATURE REVIEW

2.1 Introduction

Dynamic route guidance is very prevalent in most countries in the world today, particularly because of the remarkable technological changes in recent times. As outlined earlier, most if not all current dynamic route guidance systems employ ATMS and ATIS technologies in their operations. The first section of the literature describes the state-of-the-art of the ATMS and ATIS technologies and their importance in providing route guidance information to motorists. This was followed by the description of some of the currently available dynamic route guidance systems. The third section of the literature review discusses the evaluation of benefits of dynamic guidance systems and the fourth section gives a general outline of some methodologies for evaluating information and information systems.
2.2 State-of-the-Art of ATMS and ATIS

2.2.1 Advanced Traffic Management Systems (ATMS)

As outlined earlier, Advanced Traffic Management Systems (ATMS) employ innovative technologies and integrate new and existing traffic management and control systems in order to be responsive to dynamic traffic conditions while servicing all modes of transportation. *IVHS America 1992*. It will integrate management of various roadway functions, including freeway ramp metering and arterial signal control. The long term goals for ATMS is a fully integrated, interactive, and adaptive system, characterized by the following:

- Integration of all modes of transportation, jurisdictions, and traffic management functions.
- Support of proactive control.
- Fully automated data collection, congestion prediction, traffic control implementation, toll collection, and communication of traffic conditions.
- Automated incident management.
- An integrated database structure to support planning at all levels of decision making.

The major components of ATMS include surveillance, communication systems and control systems. The surveillance system is used to monitor and report traffic conditions, while the communication system enables traffic conditions to be reported to a traffic control center. Control measures initiated at the traffic control center will then be communicated to the roadway or vehicle. The traffic management center processes the
reported information as well as information from other sources so as to initiate suitable control measures.

The primary characteristics of ATMS can be outlined as follows:

- Collection of real-time traffic data.
- Reaction to changes in traffic flow with real-time traffic management strategies.
- Area-wide surveillance and detection systems.
- Integration of the management of various traffic control functions, including transportation information, demand management, freeway ramp metering, automated electronic toll collection and arterial signal control.
- Rapid response incident management strategies.

2.2.2 Advanced Traveler Information Systems

Advanced Traveler Information Systems (ATIS) acquire, analyze, communicate and present information to assist surface transportation travelers in moving from a starting location (origin) to their desired destination (IVHS America 1992). A major component of ATIS is providing information to the driver of a vehicle without utilizing any support from outside the vehicle (autonomously). ATIS can employ visual and auditory presentations to inform drivers of their current locations, aid them in planning their routes, help guide them to their desired destinations, and provide various informational services. With ATMS alone rerouting information can be transmitted to drivers through variable message signs, cellular phones etc. ATIS may also be used to provide communication between the vehicle and an ATMS that provides continuous information to

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the driver regarding traffic conditions, roadway congestion, alternate routes, parking and other up-to-date information.

Specifically ATIS features and products include the following:

- Navigation systems with electronic vehicle or traveler position determination.
- Data communication: transceivers providing information to, and receiving information from, traffic management centers.
- Route planning and guidance systems.
- Automated vehicle identification (AVI) systems for uses such as transit vehicle tracking or commercial vehicle credential processing.
- Flexible driver visual interface for displaying maps or traffic information
- Warning systems for various operational and maintenance conditions on transit, commercial, or private vehicles.
- Emergency (Mayday) services with signaling and response capabilities.
- A wide variety of data bases, including detailed maps, business directories, transit schedules, tourist information and the location of various services.
- Integrated ATIS/AVCS (Advanced Vehicle Control Systems) that channel AVCS control and driver condition warnings through the ATIS.
- Dynamic route guidance that can reroute vehicles around traffic congestion or incidents.
2.3 Dynamic Route Guidance Systems

Several dynamic route guidance systems are in operation in the world today (IVHS America 1992, Harris and Sadler 1989, Drew 1993, Hobeika and Subramaniam 1994). Some of these systems are in-vehicle based and others infrastructure based. The in-vehicle based category employs features within the vehicle together with traffic information to plan its route. With the in-vehicle based system, route planning is particularly achieved through the use of a digital map which is stored on a computer system in the vehicle. An on-board navigation system based on GPS or other in-vehicle location system, automatically determines and displays the location of the vehicle. When the motorist specifies a destination, the route guidance system within the vehicle selects and displays the best routes from the current location to the motorist's destination.

The infrastructure based system however, utilizes dynamic route guidance information from a traffic control or management center. With this system a computer stores the map of local link network in the area covered by the system. In addition, the prevailing road link travel times based upon road status information and actual link travel times are also stored by the system. The centralized computer selects best routes based on actual road status and traffic data, and generate guidance instructions for the participating vehicles to complete their trips. The instructions are usually transmitted to the participating vehicles by roadside beacons, changeable message signs and other roadside devices.
2.3.1 **Infrastructure Based Dynamic Route Guidance Systems**

Some infrastructure-based dynamic route guidance systems have been summarized in the following discussions (*Romuld 1991*).

**AUTOGUIDE**

A popular infrastructure based dynamic route guidance project in London is the AUTOGUIDE. This is an on-board system, which combines in-vehicle motorist information system and control center operation to guide motorists to their destinations through recommended routes. Electronic signposts/beacons receive transmissions of a vehicle’s travel time over the route and pass it on to the control center. These information are used by the control center to generate relevant routing data which is transmitted back to all equipped vehicles. With this design, there is a continuos update of system status and recommended routes which are always provided to the motorists. The operation of the system is such that, all vehicles passing a particular beacon at a particular time receive the same set of data through a communications link based on infrared pulses giving a high data rate.

**ALI-SCOUT/LISB**

The Ali-Scout/Lisb is an infrastructure based dynamic route guidance system developed by the Germans. By means of infrared transmitters and receivers, the system transfers route guidance information between roadside beacons and on-board displays in the participating vehicles. The vehicles receive routing information from a centrally located traffic guidance computer as they pass by infrared communications beacons installed at some strategic locations in the road network. The received information consists of a route
tree which recommends the best routes based on current traffic conditions from the present location of the vehicle to various destination zones. Based on the destination input by the driver, an on-board equipment provides the motorist with the best route to get to the destination.

**INF-FLUX**

INF-FLUX is a planned infrastructure based dynamic route guidance project by the French. With the use of infrared beacons installed in Paris, the system will provide a detailed traffic monitoring system. A special terminal has been designed which will allow a driver to input some details of his preferred route. The driver will be informed by the means of a system known as the Radio Data System (RDS) about which of the selected routes are currently congested.

**PROMETHEUS**

PROMETHEUS is a dynamic route guidance program which is geared towards developing a European-wide traffic management and control system. It will employ three major levels of information transfer or communication-intelligent driver aids on-board the vehicle, communication networks between vehicles, and communication and information systems that link vehicle and roadside facilities using three major levels of information transfer or communication.

Some other infrastructure based dynamic systems include; ROMANSE (Road Management System for Europe), DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) and also the TRAFFIC master in England.
2.3.2 In-Vehicle Based Dynamic Route Guidance Systems

Some of the popular in-vehicle based dynamic route guidance systems have been described below.

**PATHFINDER**

PATHFINDER, an in-vehicle based route guidance system in California is the first operational field test of a route guidance system in the United States. Drivers of specially equipped vehicles are provided with navigation systems, real-time traffic information and suggested alternate routes. Congestion and route guidance information is transmitted to motorists from a control center in the form of an electronic map shown on a display screen.

**ADVANCE**

ADVANCE has been established to field test many aspects of dynamic route guidance. It has the following features:

- Distributed intelligence (all route planning is performed in the vehicle)
- An hierarchical road network database (for higher performance in all map-related functions)
- Vehicle as traffic probe (for accumulating real-time information)

The routing strategies of ADVANCE are as follows: The fastest route to the destination is calculated based on historical traffic patterns contained on the CD-ROM and real-time traffic data broadcast from the TIC (Traffic Information Center). The user can set up a trip with multiple destinations, and save a trip for later recall. The user can also specify
detours which encourage or discourage the use of a particular road in the selection of a route. The user also elect to avoid freeway toll ways, and particular localities. In addition to finding fastest route, the user can specify the shortest path or the route with the fewest maneuvers. These preference can be applied to all trips for a particular driver or to a particular leg of a trip.
RACS (Road/Automobile Communication System)

RACS consists of roadside communication units (beacons), on-board vehicle units and a system center. RACS collects and disseminate information between roadside beacon and vehicles. The system is based on the newly developed intermittent two-way digital mobile communication system using microwaves. The system functions are classified into navigation, roadside information and message systems.

Many other popular in-vehicle based systems include TravELGuide by the Canadians, AMTICS (Advanced Mobile Traffic Information and Communication System) and CACS.(Comprehensive Automobile Traffic Control System) by the Japanese.

2.4 Dynamic Route Guidance Control Strategies

Dynamically routing motorists through a transportation network from their origins to destination could be based on any one of two approaches. These approaches are the user optimal approach and the system optimal approach.

2.4.1 User Optimal Approach

The user optimal approach follows a principle which was first introduced by Wardrop (1952). This principle says: “The journey time on all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route.”
This criterion is a likely criterion since it is reasonable to assume that every motorist will try to minimize his or her travel time when traveling from origin to destination. This does not however mean that all travelers between each origin and destination pair should be assigned to a single path. The travel time on each link changes with the flow and therefore, the travel time on several of the network paths changes as the link flows change. A stable condition is reached only when no traveler can improve his travel time by unilaterally changing routes. This is the characterization of the user-equilibrium (UE) condition.

Since individual motorists can be expected to behave independently, the UE situation ensures that at this point there is no force that tends to move the flows out of the equilibrium situation. As a result this point will be stable and in fact, a true equilibrium.

The user equilibrium approach was first formulated as a mathematical optimization problem by Beckmann et al (1956) and can be summarized as follows;

Given a transportation network with N nodes and K links, the user optimum assignment is formulated as:

\[
\text{min} Z_1 (f) = \sum_k c_k (w) dw \\
\text{subject to:} \\
\sum_q f_{pq} = q_{od} \\
f_k \geq 0
\]

where:
\( q_{od} = \) the number of trips from origin o to destination d

\( f^o_d = \) number of trips between origin o and destination d that use path p

\( f_k = \) flow on link k

\( C_k (w) = \) the travel time experienced by each driver on link k as a function of flow.

A simple user equilibrium approach is illustrated using Figure 2.1. Figure 2.1a shows a network representing one origin-destination pair connected by two alternative routes. Let \( t_1 \) and \( t_2 \) represent the travel time on links 1 and 2, respectively, and let \( x_1 \) and \( x_2 \) represent the flow on the links. The total origin-destination flow is designated by \( q \), where

\[
q = x_1 + x_2
\]  \hspace{1cm} [2.2]

The performance functions on these links \( t_1(x_1) \) and \( t_2(x_2) \) are shown in Figure 2.1b. For each link, the performance function represents the travel time on that link as function of the flow on the link.

If the trip rate \( q \) between O and D is very small and all motorists are trying to minimize their own travel time, each of the \( q \) motorists should choose to travel over link 1, since link 1 has a lower travel time associated with it than link 2 as shown in the figure. If \( q \) is small, the increased delay due to the traffic on link 1 is not sufficient to increase the travel time on this link even to the point where it is equal to the free-flow travel time on link 2. Thus, all \( q \) motorists will use link 1 and no one will use link 2. This therefore represents an equilibrium situation since none of the motorists using link 1 has an alternative to switch routes to the longer link. Such an equilibrium will hold as long as \( q < q' \), where \( q' \) is the flow that causes the travel time on link 1 to equal the free flow travel time on link 2.
At this point, an additional motorist may choose either link. If the additional motorist chooses link 2, the travel time on it will increase and the next motorist will choose link 1. If on the other hand the motorist (above q') chooses link 1, the next one will choose link 2.

Considering the flow of traffic as a continuous flow, it is clear that beyond the point q=q', equilibrium can be maintained only if the travel time on both links is equal. Beyond this point both links are used, and if the travel times are not equal, some motorists can change route and lower their own travel time. The route switching process will not occur only if the travel time on both routes is equal, giving motorists no incentive to switch.

2.4.2 **System Optimal Approach**

Unlike the user optimal approach which minimizes individual motorist travel times, the system optimal approach seeks to minimize the total travel time on the network. The flow patterns in the system optimal route diversion strategies therefore do not generally represent an equilibrium situation. The system optimal approach can mathematically be formulated as follows:

\[
\text{Min } Z_2 (f_k) = \sum_k f_k C_k \tag{2.3}
\]

*subject to:*

\[
\sum_q f_{q_i}^{od} = q_{od}
\]

\[
f_k \geq 0
\]
In general, obtaining system optimal conditions may conflict with individual user objectives. However, information provided to motorists can be altered so as to indirectly force them towards system optimal routing conditions as opposed to user optimal.
Figure 2.1  User equilibrium in a simple network: (a) a two link network; (b) the two performance functions - if the flow is less than $q' = x_1 + x_2$, it is assigned to link 1; (c) the travel time on both links is equal if the flow is higher than $q'$
2.5 Benefits Evaluation of Dynamic Route Guidance Systems

Several studies, some of which have been summarized in the previous section, generally acknowledge the fact that traffic information to motorists improves the general performance of road transport networks, in terms of minimizing driver travel times, smoothening traffic flows and maximizing the general use of the highway network. Several works adopted different approaches for evaluating the effects of information in road transport networks.

*Tsuji et al. (1989)* investigate the effectiveness of route guidance systems by using a mathematical model and applying it to a case study in the area of Tokyo. They use as a measure of effectiveness the probability that guided vehicles arrive at their destination before unguided vehicles and the percentage of travel time reduction for guided vehicles. Based on their model, guided vehicles arrive at their destination earlier with probability 0.85 and experience an 11% reduction in travel time. Their model however suffers from several drawbacks such as: non-sensitivity to the type of information that is transmitted to the users, non-inclusion of interactions between guided and unguided vehicles and insensitivity to the percent of guided and unguided vehicles. These drawbacks resulted from the following simplifying assumptions made in their model such as:

- Flow of guided vehicles does not affect the remaining traffic flow
- Travel times on alternate route are mutually independent
- Only two alternate routes exist and each route is used by the guided vehicles or only by the unguided vehicle
- Travel time and predicted travel time are normally distributed and are independent
• All users follow route recommendations

Al-Deek et al (1989) estimated potential benefits of in-vehicle information systems in the context of the PATHFINDER project. They conducted a survey to identify routes typically used by commuters in a portion of the SMART corridor in Los Angeles. They simulated traffic along that corridor and used FREQ6PC and TRANSYT-7F to determine travel times on the network links. for a combination of four origin and three destination intersections the cost of different routes was estimated based on the following criteria: shortest path, freeway-biased route and arterial-biased route. It was assumed that drivers with perfect traffic information would follow the shortest path to their destination. Based on these assumptions, it was found that savings in travel time estimates based on the difference between the shortest path and the other paths are only about 3 minutes for a 20-25 minute trip for the case of a recurring congestion. They found that under the conditions of their analysis, maximum savings of 10 minutes may be realized for a 30 minute trip.

Mahmassani et al (1989) also address the question of existence of opportunities to improve traffic conditions by provision of real time information to motorists. They collected data on travel times along three alternative routes for different departure times for a given origin destination pair on a corridor in Austin, Texas. Based on the differences in travel times along those routes, they concluded that travel time may be reduced by 15% to 30% through route change and by 10% to 22% through departure time switching.

Koutsopoulos and Lotan (1989) presented a methodology to analyze the effectiveness of motorist information systems in reducing recurrent traffic congestions. The methodology
is based on the assumption that provision of information affects the perception users have on link travel times of a network and therefore improves their route choice. In their model, they assumed that travel time on a link follows a normal distribution with mean $t_a(x_a)$ and standard deviation $\beta t_a(x_a)$, with $\beta$ being the coefficient of variation. Thus a value of $\beta = 0.0$, represents zero standard deviation or a situation of complete information and $\beta = 0.5$ represents the standard deviation being equal to actual travel time or complete lack of information. The function used for the link travel time is the BPR function given as:

$$t_a(x_a) = t_a^0 [1 + 0.15(x_a/cap_a)^4]$$

[2.4]

where:

$t_a^0$ is the free flow travel time on link $a$

$x_a$ is the flow in link $a$

$cap_a$ is the capacity of link $a$.

The model was applied to a relatively small suburban network using data from the city of Sudbury, Massachusetts. It was found that there is a 4.4% reduction in average travel time as the coefficient of variation decreases from its highest value of 0.5 to 0.0

Spasovic et al (1995) developed a framework for assessing the benefits of highway traveler information services. They determined the value of information to a traveler as the difference between the expected travel time with perfect information and the expected travel time with prior (a priori) information. The approach assumes that a decision maker may undertake action from the set of all possible actions $A = (a_1, a_2, a_3, ..., a_n)$. There are several states of nature $x_i$ that can occur. They are included in the set $X = (x_1, x_2,$
Each state occurs with probability $p_i(x_i)$. For each action $a_k$ that is undertaken when the state of nature $x_i$ occurs, the decision maker receives a payoff (a reward or a loss), $V_{ki}(a_k, x_i)$. The states of nature refer to traffic situations prevailing on a particular route such as normal traffic conditions or congested traffic conditions. The actions refer to the choice of routes. In general the decision maker-traveler will try to optimize the expected value of his/her gain function. In this case, he/she minimizes the expected travel time of choosing action $k$ when the state of nature $i$ occurs over the set of actions. This is obtained by:

$$E[V(a, x)] = \min_k \sum p(x_i) * V(a_k, x_i)$$  \[2.5\]

The expected gain with perfect information $E[PI]$, where the traveler selects $k$ to maximize $V(a_k, x_i)$ for each $x_i$, is given as:

$$E[PI] = \sum p(x_i) * \min_k V(a_k, x_i)$$  \[2.6\]

The value of information to the traveler is based on the difference between the expected travel time with perfect information and the expected travel time with prior (a priori) information.
2.5.1 Benefits of Some Dynamic Motorist Guidance Systems

In this section, some of the motorist guidance systems in the United States which have been evaluated over time have been discussed (Hobeika and Subramaniam 1994).

INFORM in New York is an information system covering the busy 35-mile central corridor in Long Island and is claimed to be the nation’s largest and most advanced traffic information system for motorists. It is currently, the only traffic management system that combines control of both freeway and arterial roadways to optimize traffic routing and efficiency. Its main functions include the following:

- Keep drivers informed of traffic conditions ahead through computerized traffic message signs
- Alert police and other agencies in the event of delay causing accidents or other incidents
- Perform many traffic light operations at ramp entries and exits to smoothen traffic flow and traffic back-ups.

The Virginia DOT’s Traffic Management System comprises mainly of two interstates in Northern Virginia, namely, I-395 and I-66. These form part of a comprehensive traffic management system of Virginia Department of Transportation. The system consists of a computerized freeway and control system which controls seventy-two changeable message signs. The system has the objective of reducing traffic congestion, eliminating bottlenecks and reducing incident detection time.
In Minnesota, the Department of Transportation is currently upgrading a Transportation management Center to support its Guidestar program. The Guidestar program has the objective of integrating ongoing ATMS and ATIS efforts with a wide range of new ITS technologies with the purpose of gathering traffic information and distributing it to traffic managers and motorists. Minnesota ATMS system, evaluated after 10 years of operation produce the following results:

- 35% increase in average peak period freeway speeds
- 32% increase in peak period volumes
- 38% decline in peak period accident rates

The Los Angeles Automated Traffic Surveillance and Control (ATSAC) system encompasses 118 intersections and 396 detectors in a 4 square mile area located 5 miles from the ATSAC control center. Two major freeways pass through the control area, the Santa Monica freeway on the north and the Harbor freeway on the south. The project has the objective of integrating freeway surveillance, control and computerized signal systems with various traveler information technologies, including highway advisory radio (HAR), changeable message signs, kiosks and telex.

The second phase of the system concentrates on the Los Angeles CBD comprising of 162 intersection signals, 49 mid-block signals, and 800 detectors. The third and fourth phases are currently under design and should be fully implemented soon.

The benefits from the program include:

- 13% reduction in vehicle delays;
- 35% reduction in vehicle stops;
• 14% increase in average speed;
• 20% decrease in intersection delay;
• 12.5% decrease in fuel consumption

2.6 General Procedures for Measuring Information

In assessing the value of information or an information system, several factors are considered, most of which are specific to the system under consideration. Many researchers have studied the evaluation of information and information systems. These studies range from evaluating the output of an existing information system to justifying the implementation of a new decision support system.

Several researchers have studied cost/benefit analyses of information systems. Keim and Janaro (1982) extended the work of Hirsch (1968) to develop a phased approach to cost/benefit analysis. Other people have studied alternatives to traditional cost/benefit analyses. (Lindgren, 1981). Smith (1983) reviews four approaches: Incremental Analysis, Expected value, Value analysis and Benefit profile. Gage (1986) and Keen (1975) recommend value analysis since it allows qualitative benefits to be considered without having to relate them directly to costs.


The most common approaches to the assessment of the value of information can be classified into three main groups namely (i) the realistic value approach, (ii) the normative approach and (iii) the subjective approach. Each of these has been briefly summarized in the following discussions.

2.6.1 The Realistic Value Approach

With this approach the value of information is the change in actual performance due to the introduction of the information system. The value of information is measured in terms of performance and therefore may be multidimensional. This approach though conceptually simple, is not always feasible, since it is not always possible to prove a direct relation between new information and change in performance. The realistic value approach becomes more difficult upon the recognition that the value of information must be known in advance before introducing the information system. Hence the realistic value approach is very useful in evaluating existing information systems.
2.6.2 The Normative Approach

The normative approach of measuring the value of information involves calculation using a quantitative model of the relation between outcome measures and information. To do this, a model of the system is needed. The approaches to modeling are either analytic or simulative. The most comprehensive analytic approach usually adopted is “Information Economics” which combines decision theory and utility theory to calculate the expected utility of a given information system. Information Economics assumes that the value of information can be assessed from users’ perceptions encoded into event probabilities and utility values assigned to possible outcomes of decisions. An information system is viewed as a probabilistic mapping from the set of possible events to a set of possible signals. The results of such a model are only relative values of information. There are other analytic modeling of less general nature which use the concept of control theory. (Davis 1974, Demski 1972). Zmud (1978) comments on the information economics approach: “Theoretically, the information economics approach is very appealing; realistically, it appears impractical.” King and Epstein (1976) attempt to make the information economics approach more practical by developing an operational approximation.

Two kinds of simulation models are normally employed in the normative approach. In one form a system model is built with decision rules incorporated, such that the system performance is evaluated under changing features of the of the input information. In a second form, decisions are made by human “decision makers” and performance is measured as a function of the information provided to them (Langeors 1977).
A major disadvantage of the normative approach is that since it is based on modeling, it may be very difficult to apply in situations which are not fully structured.

2.6.3 The Subjective Approach

As the name suggests, in the subjective approach users are asked questions to evaluate some given information sets directly. The evaluation tool could be in a form of a set of questions related to the various characteristics of the users. The main justification for this approach is that it combines the expertise and heuristic understanding of the users and implicitly incorporates human factors. These human factors include individual cognitive style as well as factors which may improve decision making environment without really being needed for a given decision. (Davis 1974). The major advantage of this approach is that it is relatively easy to conduct. The main disadvantage is that there is no direct relation between results and any “real value” of information. They have the usual deficiencies of all subjective evaluations, such as semantic problems (possibility of fuzzy meaning) and inter-dependent data. By its nature subjective evaluation is a purely relative tool. However they can be used for comparative analysis. Instruments have been developed by some researchers for the subjective evaluation of information and information systems. (Blaylock et al 1984, Szewczak et al 1987). These instruments measure user perceptions of various attributes of information systems or the information output from the systems.
CHAPTER III
RESEARCH METHODOLOGY

Several methods for evaluating information systems have been outlined in the previous chapter. The suitability of any of the methods for a particular system depends primarily on the characteristics of the system and other factors such as the ability to model the system. This research has the primary objective of formulating a methodology for estimating the utility of information at potential information location sites along freeway corridors and also to develop a computer model based on the methodology. The computer model is a general purpose tool capable of estimating the utility of information on different links along freeway corridors within any transportation network.

3.1 Formulation of Methodology For estimating Utility of Information

Provision of information to motorists is most useful, when motorists are faced with congested traffic situations on one part of a network and there is a possibility of less congested alternate routes which they could have used. Thus the methodology for estimating the utility of information has been based on the two major causes of congestion: Recurrent and Non Recurrent congestions.

The logic used in developing the methodology for estimating the utility of information at potential information sites along freeway corridors is solely based on the idea that, there is a possibility of existence of other routes on the arterials for the freeway users to get from an upstream node of the freeway to the downstream node of the freeway if they
know of the existence of such routes. The implication is that motorists would prefer to choose such routes if they offer a higher utility than going on the freeway. Thus this approach will seek to maximize the utility of freeway users by diverting them onto parallel alternate arterial routes to the freeway links that offer a higher level of utility. As illustrated in Figure 3.1, a motorist traveling on the freeway section from point N to S could reduce disutility of travel if information is presented to him/her about the prevailing conditions on other alternate routes. For example in traveling from point N to point S, the motorist has to traverse the freeway link L2 if he/she is traveling on the freeway. However, if the link L2 happens to be very congested, the motorist could reduce the disutility of travel by using other uncongested alternate routes to the link L2, such as the routes formed by arterial links AB, BC and CD or AB, BE, EF, FC, and CD. Thus if the route ABCD formed by the arterial system gives a lower disutility than going directly from A to D or using any other alternate routes formed by the arterial system, the motorist will most probably travel from A to D using route ABCD. Nevertheless, the motorist can only take advantage of this possibility if he/she knows of the situation on these alternate routes.
Figure 3.1 Illustration of the research methodology (Part 1)
In accordance with rational expectations, an individual motorist will travel by routes that offer him the maximum utility. A general utility function has the following form:

\[ U_v = \beta_1 \chi_{ij}^1 + \beta_2 \chi_{ij}^2 + \ldots + \beta_n \chi_{ij}^n. \]  

[3.1]

where:

- \( U_v \) = utility individual \( i \) associates with alternative \( j \)
- \( \chi_{ij}^k \) = \( k \)th attribute of alternative \( j \) of individual \( i \).

Typically, the utility function used in route choice decision making is based on the following:

- travel time
- distance
- fuel consumption and other out of pocket expenses
- route convenience and other factors

Strictly speaking, most of above factors are in one way or the other directly or indirectly related to the motorists travel time. Therefore, for the purposes of this research and the difficulty in modeling all the other factors the utility function of Equation 3.1 can be reduced into a form where it is only a function of travel time. This is given as:

\[ U = f(T) \]  

[3.2]

where:

\( U = \) utility
\[ f(T) = \text{function of travel time savings.} \]

Thus if travel time information on a freeway link versus the travel times on alternate routes from the upstream node of the freeway link to the downstream of the freeway link using arterial links is presented to the motorist, a rational motorist will choose the route that offers him/her the maximum utility. In other words, the motorist chooses the route that offers him the greatest reasonable savings in travel time over using the freeway link, else the motorist continues on the freeway. The diversion of a motorist from a freeway link to an alternate route to the freeway link any time follows the simple expression of:

\[ P^* = \min (P_t \ \forall P \in S) \quad [3.3] \]

where:

\( S = \text{set of all routes available to the motorist at the time of making a route choice decisions including the freeway link} \)

\( P = \text{any path belonging to the set} \ S \)

\( P_t = \text{travel time on path} \ P \ \text{belonging to} \ S \)

\( P^* = \text{Path in set} \ S \ \text{with the least disutility or travel time} \)

The logic follows that, if information is presented to motorists, their route choices follow the user equilibrium assignment procedure. That is motorists will continue to divert from one link to the other until there cannot be any more savings in travel time by diverting to any other route. On the other hand, the objective of a transportation planner or engineer in trying to solve traffic congestion problems is essentially based on the net gain by all
the motorists affected by the information presented to them. This is equivalent to saying that the system planner evaluates the utility of information based on system optimal assignment approach. Thus the utility function of Equation 3.2 will be based on the transportation planner’s/engineer’s perspective of evaluating the benefits of information. Hence $T_r$ in Equation 3.2 is the net gain in travel time of all the motorists affected by the presentation of the information. Therefore if number of vehicles $dV$ changed routes by diverting from using freeway link F2 on freeway I-I onto an arterial route R formed by arterial links (see Figure 3.2) as a result of information presented to the motorist on an a freeway link F1 which is upstream of F2, a typical utility value for the utility of information presented on link F1 as will be evaluated planner/engineer can be given by Equation 3.4.

$$U = f(T_r) = M_f * V_{fr} + dV * T_{fr} - \left[ \sum_{i=1}^{M_a} M_a V_{ai} + dV * T_{ai} \right]$$  \hspace{1cm} \text{[3.4]}

where:

$M_f$ = benefit of removing $dV$ vehicles from freeway (change in freeway travel time)

$V_{fr}$ = volume of traffic using freeway prior to diversion

$dV$ = volume of traffic that got diverted from freeway

$T_{fr}$ = average freeway travel time after diversion

$M_{ai}$ = cost (change in arterial link travel time) of adding $dV$ vehicles to arterial link i on diversion route

$V_{ai}$ = volume of vehicle on arterial link i of diversion route prior to diversion

$T_{ai}$ = average travel time on arterial link i after diversion

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Figure 3.2  Illustration of the research methodology (Part 2)
Since any transportation network and for that matter a link in a transportation network is subject to either recurrent or non recurrent congestion, the most appropriate approach towards the development of a methodology hence a computer model for estimating the utility of information to motorists should be based on both recurrent and non recurrent traffic congestion. In this research the computer model that has been developed for estimating the utility of travel time information on freeway links consists of three components. One component evaluates utility of information based only on recurrent traffic congestion situations. A second one evaluates the utility of travel time information based only on non recurrent traffic conditions and the third one is the combination of both the recurrent and the non-recurrent models to produce a single result.

In general, a methodology based on a non recurrent traffic congestion or recurrent traffic congestion follows the same basic structure as described in the previous sections. However, there are some characteristics peculiar to each of these approaches. The characteristics of each of these approaches have been summarized in the following discussions.

3.1.1 Information Utility Based on Non-Recurrent Congestion

Non-recurrent traffic congestion as outlined in the introduction occurs due to an incident or other event which blocks freeway lanes and reduces capacity. Several elements are considered in diverting traffic during incident conditions. These include:

- Volume of traffic to be diverted
- Starting point of the diversion
• Termination point of the diversion
• Diversion routes

The methodology of this research has been based on historical peak period traffic volumes in order to take care of worst case scenarios. Under incident conditions, the diversion route has been assumed to be a static diversion route with the least travel time.

Also, depending on the traffic conditions and the traffic flow variables, the appropriate diversion strategy is adopted. The diversion strategy could be any of the following types:
• No Diversion
• Point Diversion
• Corridor Wide Diversion
• Inter-Freeway Diversion

The no diversion base case, is a strategy that may be appropriate when the incident delay is not significant, or when the alternate routes themselves are congested. Point diversion is a strategy that diverts the traffic from the exit ramp immediately preceding the incident link, to the entry ramp immediately following the incident link. In cases when this strategy may not be the most appropriate the corridor wide strategy attempts to divert motorists from a few exits upstream of the incident to a few exits downstream of the incident. In event of a very major incident that causes several freeway links to be closed for long periods of time, an Inter-Freeway Diversion strategy to divert traffic from one freeway to another, may be appropriate.
In this research, the diversion strategies, have been limited to the No diversion and the Point diversion cases. The earlier discussions suggests that the motorists will themselves not choose an alternate route to a freeway link if they will not achieve any reasonable savings in travel time by changing routes (no diversion), else they will divert based on the point diversion strategy. The diversion route with the non-recurrent congestion situation is the arterial route with the least travel time (P*). The background for this being that, currently the Virginia Department of Transportation (VDOT) incident management strategies adopt only a single static diversion route. Thus the methodology assumes that traffic will distribute between the freeway link and the route P* according to the user equilibrium assignment method as long as the freeway link travel time is higher than the travel time on P*. The logic of this methodology is given by the flow chart in Figure 3.3.

The random nature of incidents and the difficulty in modeling incidents present another big challenge in attempting to evaluate and rank freeway links based on utility of information presented to motorists on the freeway links. Assuming the same incident type X occurred on downstream links of two freeway links A and B and travel time benefits by traffic diversion under the incident conditions have been simulated to be the same on both links. Then the frequency of incidents on the downstream link of each link is an important factor that needs to be considered in deciding which of the two links should be preferred if information should be located on only one of the two. The method considered appropriate and adopted in this research is the usage of a database of incident history. The database provides information on the incident characteristics of the freeway links (durations), over a given period of time that the analyst considers useful.
The total duration of incidents on a given freeway link also captures the level of incident severity on that link. A link with significantly higher incident duration than another could reflect how far the link on the network is from incident clearing agents or the kind of incidents that occur on the link hence take so long to clear. For example spillage of hazardous chemicals. Therefore in general, a link with high incident hours will require more information display at its upstream as compared to a link with low incident hours. In estimating the relative utility of information on the links along a freeway corridor therefore, the incident hours has to be incorporated in the expression. The higher the number of incidents or total duration of all incidents on a particular link, the greater the likelihood of the usefulness of travel time information delivered on the link upstream of that incident link. This stems from the fact that information will be in a higher demand on such a link in order to divert traffic from getting onto the congested freeway incident link.

Also, the database contains information on the average number of lanes blocked on a particular link, which is also an important indicator of incident severity. The methodology assumes that the freeway link capacity is reduced by the average number of lanes blocked by incidents (ratio of sum of lanes blocked to total number of incidents on the link). This means that information delivered on a link which is upstream of another link with relatively high reduction in link capacity will be more useful than information delivered on a link which is upstream of another link with relatively low reduction in capacity. The reason for this is the same as indicated in the above paragraph.

Therefore if a network consists of n number of freeway links that are being considered for prioritization based on the utility of information delivered on those links, there is the
need to take into account the total number of incidents or total incident durations on those links. Hence the travel time utility need to be rationalized or normalized for a more meaningful comparison. The normalized utility value for a given link can then be written as:

\[ U^p_m = \frac{(U \times T^p)}{\sum T^p} \]  \[ 3.5 \]

\( U^p_m \) = modified utility value of freeway link \( p \)
\( U = f(T) \) = the value of utility based solely on travel time savings (as defined earlier)
\( T^p \) = total incident time (in minutes) on link \( P \) over the period of interest. That is the sum of the duration of the various incidents that occurred on link \( P \).

### 3.1.2 Information Utility Based on Recurrent Congestion

Unlike the non-recurrent traffic congestion situation, the methodology under recurrent traffic conditions has been based only on peak period traffic conditions, in which case there is no need for normalization of the utility values of information prior to making any comparisons. The same No diversion and Point diversion strategies has been employed with the recurrent congestion based model. Historical peak period traffic conditions has been used in this model too. The most important difference in the recurrent and the non-recurrent based methodologies is that, with the recurrent methodology every alternate route to the freeway link is considered as a potential diversion route. This is because there will always be continuos information to motorists on travel conditions on all possible routes. The methodology assumes that at each time in the process, traffic will
distribute between the freeway link and the arterial route (P*) which has the least travel
time according to the user equilibrium assignment method. Since it is probable that the
arterial route with the least travel time could experience an increase in travel time some
other arterial route might become the route with the least travel time hence traffic now
distributes between the new path and the freeway link. This process continues until there
is no other arterial route with a lower travel time than the freeway link. The freeway link
whose utility value will be evaluated is the freeway link upstream of the congested
freeway link, since that is where information will be provided to enable decision making
before getting on to the congested link. The logic of this methodology is given by the
flow chart in Figure 3.4. The utility value of information provided on a freeway link is
given by Equation 3.6.

\[
U = f(T_c) = M_f * V_{fr} + dV * T_{fr} - \left[ \sum_p \sum_{i=1} M_{pai} V_{pai} + dV_{pai} * T_{pai} \right]
\]  \[3.6\]

where:

\[\sum_p \sum_{i=1} dV_{pai} = dV\]

\(M_f\) = benefit of removing \(dV\) vehicles from freeway (change in freeway travel time)

\(V_{fr}\) = volume of traffic using freeway prior to diversion

\(dV_{pai}\) = volume of traffic that got diverted from freeway on to arterial link \(i\) of route \(p\)

\(T_{fr}\) = average freeway travel time after diversion

\(M_{pai}\) = cost (change in arterial link travel time) of adding \(dV_{pai}\) vehicles to arterial link \(i\)
on diversion route \(p\)

\(V_{pai}\) = volume of vehicle on arterial link \(i\) of diversion route \(p\) prior to diversion
$T_{p_{ai}} = \text{average travel time on arterial link } i\text{ of path } p\text{ after diversion}$

The additional summation sign in Equation 3.6 accounts for the likelihood of more than one path for diverting vehicles from the freeway as compared to only one path in the non recurrent traffic congestion case.
Figure 3.3  Methodology for estimating utility of information based on recurrent congestion on links along freeway corridors
Figure 3.4 Methodology for estimating utility of information based on recurrent congestion on links along freeway corridors
3.1.3 Integrated Recurrent and Non-recurrent Congestion Utility Function

As stated earlier recurrent and non-recurrent traffic congestion contribute in different proportions to total congestion. Hence a weighted sum of the recurrent and non-recurrent traffic congestion based utility values of a particular freeway link gives the actual utility value of that link. That then becomes the true utility values of the freeway links that need to be used in comparing the relative usefulness of information provision on the links, hence making decisions accordingly. Thus for a particular freeway link the value of information could be written as Equation 3.7 below:

\[ U_T = \alpha U_T^m + \beta U_T^r \]  \hspace{1cm} [3.7]

where:

- \( U_T \) = Integrated utility value based on both recurrent and non-recurrent congestions
- \( \alpha \) and \( \beta \) = parameters

The value of the weighting parameters \( \alpha \) and \( \beta \) have been chosen as 0.4 and 0.6 respectively as suggested in the literature. (Hobeika and Subramaniam, 1994)

The methodologies discussed above for the recurrent, the non recurrent and the integrated models have been built into a computer model. The computer model developed is a general model that is applicable to any network which has a freeway corridor and could be used to estimate the relative usefulness of providing information on any of the chosen freeway links. In the next chapter, the development of the computer model has been described in details.
CHAPTER IV
COMPUTER MODEL DEVELOPMENT AND APPLICATIONS

This chapter describes the computer model that has been developed based on the methodology described in the previous chapter and its applications. The model is capable of estimating the relative value of information located on links along freeway corridors. The most important usage of this computer model is that it will act as an advisor and a decision support system for transportation planners and engineers. This will enable them to make judgment on where to locate motorist information devices to achieve maximum utility. The computer model called the Information Location Advisor (ILA) has been developed using the C++ programming language.

The Information Location Advisor has been developed using the following major modules:
- Route generation module
- Travel time estimation module
- Traffic assignment module

The following discussions give the summary of the C++ language and the building modules of the Information Location Advisor.
4.1 C++ Language and Building Blocks of the ILA

4.1.1 C++ Language

The C++ language has been chosen over the many other conventional languages in the development of the Information Location Advisor because of its numerous advantages over the procedural languages.

There are many procedural languages in use today. These include BASIC, FORTRAN, Pascal and C. In conventional procedural programs, data and functions are treated as separate entities. To enable functions to access data, the data must be declared to be global, which greatly increases the chances of data being accidentally corrupted by functions. In addition, if the data structure is changed, all functions which use that data must be modified. This can be a difficult task for large programs with many functions.

The C++ programming language however, has a lot of advantages over the procedural languages. Unlike the procedural languages the C++ language is an object oriented language. The object oriented programming methodology provides a means for managing the complexity of software. In object oriented programming, both data and functions operating on that data are combined together into a single unit called an object. Such objects simulate both the characteristics and behavior of real world objects. The fundamental idea of the object oriented programming approach is to combine both data and functions into a single entity called an object. Thus, data and its functions are said to be encapsulated into an object. Data encapsulation and data hiding are the most
significant departure from procedural programming. As the name indicates, the object is
the basic concept behind object oriented programming. Objects rather than commands are
the main roles in the object oriented approach.

Objected oriented programming is not primarily concerned with the details of operation.
It deals with the overall organization of the program. The integrity of each object makes
it easier for functions to be written separately. As a result, a large program can be divided
into smaller parts, with each part having its own data and functions. This makes it
possible for different programmers to work on various parts of a large project
independently and makes software development very efficient.

4.1.2 Route Generation Module

The route generation module is the basic building block of the ILA. It determines all
feasible routes on an arterial network that could be used as an alternate route for a
particular freeway link. This means that for a given freeway link, the module will be
used to find all other possible routes from the upstream node to the downstream node of
the freeway link of interest by using arterial links. The search is very exhaustive to ensure
that all possible routes have been identified. The limit on the number of routes is that
routes are not to consist of more than six links. This is an assumption embedded in the
model against the background that routes with too many intersections are generally not
desirable to motorists. Also, a route with more than six links will generally be too long
and could be considered beyond the influence area of a congested freeway link.
4.1.3 Travel Time Estimation Module

Travel time estimation in an urban traffic network has played a fundamental role in transportation engineering. The estimation of travel time is an inevitable process in the development of the Information Location Advisor. The decision of motorists as to whether to divert from the freeway to an alternate route of arterial links or not is solely based on travel times. The use of link capacity or link performance functions have been one of the invaluable methods of deducing travel times from relating traffic variables and the static capacity of the road. The travel time module used in this research was based on the link capacity functions.

4.1.4 Link Capacity Functions

The representation of traffic networks by a set of links and nodes makes it possible to mathematically relate link travel times to traffic variables on the link. Link capacity functions have remained particularly popular because of their simplicity and consistency in estimating travel times. However for flow to capacity ratios greater than 1, reasonable travel times cannot be obtained because of the difficulty in observing travel times at such high flows. A heuristic method is employed to estimate the travel time for the link when flows are greater than the capacity. The two most used and popular link capacity functions namely; Bureau of Public Roads function (BPR) and Davidson’s model have been discussed below.
4.1.4.1 Bureau of Public Roads Function (BPR)

The BPR function assumes that the travel time on each link is dependent upon the traffic volume, the capacity, and free flow travel time which can mathematically be expressed as:

\[ T_Q = T_0 (1 + \alpha \cdot (\frac{Q}{Q_{\text{max}}})^\beta) \]  
[4.1]

where:

\( T_Q = \text{travel time at flow } Q \)
\( T_0 = \text{‘zero-flow’ travel time} \)
\( Q_{\text{max}} = \text{capacity} \)
\( Q = \text{traffic flow} \)
\( \alpha, \beta = \text{parameters} \)

\( \alpha \) and \( \beta \) values of 0.15 and 4 respectively are generally used.

4.1.4.2 Davidson’s Model

Davidson (Davidson, 1966) has developed a link performance function in terms of traffic volume and facility type. This model is asymptotic to a capacity flow based on queueing theory consideration, while BPR curves are not asymptotic to any capacity value (Khisti, 1990). The Davidson’s model is given as:
\[ T_Q = T_o \times (1 - (1 - \tau) \times (Q / Q_{\text{max}})) / (1 - (Q / Q_{\text{max}})) \]  

[4.2]

where:

\( T_Q \) = travel time at traffic flow \( Q \)  
\( T_o \) = zero-flow travel time  
\( Q \) = traffic flow (vehicle/hour)  
\( \tau \) = level-of-service parameter (LOS)

The inadequacy of the link capacity functions in estimating travel times when volume to capacity ratio is greater than 1 has necessitated the development of some empirical rules to estimate travel times at high volume to capacity ratios. The rules have been enumerated below. (Kari, 1989).

- If volume to capacity ratio is less than 1, select the minimum of 6 times free flow time and the travel times obtained from Equations 4.1 or 4.2.
- If volume to capacity ratio is between 1 and 1.5, select the minimum value of, 8 times free flow time, and the travel times obtained from Equations 4.1 and 4.2.
- If volume to capacity ratio greater than 1.5, select the minimum value of, 10 times free flow time, and the travel time obtained from Equations 4.1 and 4.2.

In this research, the BPR model has been chosen over the Davidson’s model, since the travel time estimation with the BPR function unlike the Davidson’s model is independent of the link types. This makes the BPR function simpler and more attractive. Historical traffic data have been used in estimation of the travel times.
4.1.5 Traffic Assignment Module

The traffic assignment module is invoked depending on whether the travel time on a particular freeway link is greater than the travel times on the alternate routes formed by the arterial links or not. In the model if the freeway link travel time is higher than the arterial route with the least travel time \((p^*)\), then the traffic assignment model is invoked and traffic assignment is performed between the freeway link and \(p^*\) based on the user equilibrium assignment method. As discussed in the previous chapter, for recurrent congestion situations, there is a continuous interaction between the traffic assignment module and the travel time estimation module until no other alternate route could be found which has a lower travel time than the freeway link being examined. With non recurrent congestion situations however, this process takes place between only one route (the least travel time alternate route) and the freeway link.

4.2 Model Structure and Files

In accordance with the methodology in Chapter 3, there are three components to the Information Location Advisor. One component could be used to evaluate utility of information based only on recurrent traffic congestion situations. Another component could be used for the evaluation of the utility of information based only on non recurrent congestion situations. The third component estimates the utility of information based on both recurrent and non recurrent traffic congestion situations. The use of the end model therefore depends on the needs of the analyst. An analyst who thinks recurrent congestion is not an issue could use only the non recurrent component of the model and
vice versa. All components however need to be ran if the analyst is interested in recurrent congestion and non recurrent congestion and/or the combined effects of both recurrent and non recurrent congestions.

A simplified flowchart of the interaction of the various components of the model is shown in Figure 4.1.
Figure 4.1 Interaction among the main building blocks of the Information Location Advisor
4.2.1 Organization of Relevant Model Files

There are four input files that are required for running all the models. The main or the master file contains all other file names to be used in running the model. It consists of 9 lines with each line having only one field. The lines have been described in Table 4.1. The contents and formats of the files in the main file namely freeway link characteristics file, arterial link characteristics file and the freeway incident history file have been described in Tables 4.2, 4.3 and 4.4 respectively.
Table 4.1  Description of master file

<table>
<thead>
<tr>
<th>Line</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>The first line is reserved for the file title which may consist of any alpha-numeric characters but should not exceed 100 characters in length</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>File containing information on the freeway links</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>File containing information on the arterial links</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>File containing information regarding the incident history of freeway links</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Output file for a recurrent congestion based utility of information</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>Output file for a non recurrent congestion based utility</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Output file for information utility based on both recurrent and non recurrent congestions.</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>Number of freeway links that are being analyzed for the location of information</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>Total number of freeway links in the network (although not necessary)</td>
</tr>
</tbody>
</table>

Table 4.2  Description of freeway link characteristics file

<table>
<thead>
<tr>
<th>Line</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Title of each file element</td>
</tr>
<tr>
<td>2+</td>
<td>1</td>
<td>Link number</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Initial node number of link</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Final node number of link</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Link free speed in miles per hour</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Number of lanes</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Length of lane in miles</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Lane capacity in vehicle per hour per lane</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>An indicator which is 1 if a freeway link is to be evaluated for utility of information on that link and 0 otherwise</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Peak hour volume on link as obtained from historical data</td>
</tr>
</tbody>
</table>
Table 4.3  Arterial link characteristics file

<table>
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<tr>
<th>Line</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Title of each file element</td>
</tr>
<tr>
<td>2+</td>
<td>1</td>
<td>Link number</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Initial node number of link</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Final node number of link</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Link free speed in miles per hour</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Number of lanes</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>Length of lane in miles</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Lane capacity in vehicle per hour per lane</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>All zeros (just a place holder)</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>Peak hour volume on link as obtained from historical data</td>
</tr>
</tbody>
</table>

Table 4.4  Description of historical freeway incident trend file

<table>
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<th>Line</th>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>1</td>
<td>Title of each file element</td>
</tr>
<tr>
<td>2+</td>
<td>1</td>
<td>Freeway link number</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Total incident minutes over a chosen time period</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Average number of freeway lanes blocked over the chosen time period</td>
</tr>
</tbody>
</table>
4.3 Application of ILA to Hypothetical and Real Traffic Networks

The computer model (Information Location Advisor) described in the previous chapter has been applied to a hypothetical network and a real life network. These applications show in details how the model is used.

4.3.1 Model Application to a Hypothetical Network

4.3.1.1 Description of the hypothetical network

The ILA computer model has been applied to a hypothetical network shown in Figure 4.1. This hypothetical network consists of 51 one way links and 26 nodes. A high speed freeway H-H runs through the center of the network, surrounded by arterial links. Each link in the network consists of two lanes.

The input files have been shown in Tables 4.5, 4.6, 4.7 and 4.8. The conversion for coding the input files is that the link numbers should be coded sequentially. The lower link numbers should apply to the freeway links and of the freeway link numbers, the lower link numbers should apply to the links that need to be analyzed. The traffic volumes assigned to the networks (called historical traffic volumes) have been randomly chosen, however with some judgment based on similar works in the past. The incident minutes in the incident history file although randomly assigned to the links have been based on the assumption that 4 incidents occured on each link and it takes a minimum of
30 minutes and a maximum of 180 minutes (3 hours) to clear an incident. The 30 minute incident clearance time has been assumed as a representative value of mild incidents which are incidents that take less than two hours to clear. Also, the 3 hours (180 minutes) represent severe incidents which are incidents that take more than two hours to clear. Thus, for example link number 7 which has the lowest incident minutes has been assumed to experience 4 incidents with each incident taking 30 minutes to clear. Also, link number 3 which has the highest incident minutes has been assumed to experience 4 incidents with each incident taking 180 minutes to clear. The incident minutes of the rest of the links have therefore been chosen between the highest value for the link number 3 and the lowest value for the link number 7. It must be noted that the utility value of providing traffic information on a given freeway link under non recurrent congestions is influenced by the incident minutes on the downstream link of that given link, but not on the link itself. As discussed in Chapter 3, the diversion of a vehicle from a freeway onto alternate arterial routes depends on the conditions prevailing on the downstream links.
Figure 4.1   Hypothetical traffic network
Table 4.5  Master file for the hypothetical network

<table>
<thead>
<tr>
<th>master input file</th>
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<tbody>
<tr>
<td>freeway.dat</td>
</tr>
<tr>
<td>arterial.dat</td>
</tr>
<tr>
<td>incident.dat</td>
</tr>
<tr>
<td>recur.out</td>
</tr>
<tr>
<td>nonrecur.out</td>
</tr>
<tr>
<td>combine.out</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

Table 4.6  Freeway link descriptor file for the hypothetical network

<table>
<thead>
<tr>
<th>Link no.</th>
<th>From node</th>
<th>To node</th>
<th>Free speed</th>
<th>No. of lanes</th>
<th>Link length</th>
<th>Capacity</th>
<th>Index</th>
<th>Peak hour vol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>70</td>
<td>2</td>
<td>3.5</td>
<td>2400</td>
<td>0</td>
<td>2800</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4</td>
<td>70</td>
<td>2</td>
<td>3.5</td>
<td>2400</td>
<td>0</td>
<td>2500</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>6</td>
<td>70</td>
<td>2</td>
<td>3.0</td>
<td>2400</td>
<td>0</td>
<td>1700</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>7</td>
<td>70</td>
<td>2</td>
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</tr>
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<td>7</td>
<td>9</td>
<td>70</td>
<td>2</td>
<td>2.5</td>
<td>2400</td>
<td>0</td>
<td>1800</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>11</td>
<td>70</td>
<td>2</td>
<td>3.5</td>
<td>2400</td>
<td>0</td>
<td>1500</td>
</tr>
<tr>
<td>7</td>
<td>11</td>
<td>12</td>
<td>70</td>
<td>2</td>
<td>2.5</td>
<td>2400</td>
<td>0</td>
<td>2850</td>
</tr>
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<td>12</td>
<td>14</td>
<td>70</td>
<td>2</td>
<td>2.5</td>
<td>2400</td>
<td>0</td>
<td>2860</td>
</tr>
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<td>9</td>
<td>14</td>
<td>16</td>
<td>70</td>
<td>2</td>
<td>3.5</td>
<td>2400</td>
<td>0</td>
<td>2300</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>17</td>
<td>70</td>
<td>2</td>
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<td>2400</td>
<td>0</td>
<td>1900</td>
</tr>
</tbody>
</table>
Table 4.7  Arterial link descriptor file for the hypothetical network

<table>
<thead>
<tr>
<th>Link no.</th>
<th>From node</th>
<th>To node</th>
<th>Free speed</th>
<th>No. of lanes</th>
<th>Link length</th>
<th>Capacity</th>
<th>Index</th>
<th>Peak hour vol</th>
</tr>
</thead>
<tbody>
<tr>
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<td>750</td>
</tr>
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<td>60</td>
<td>2</td>
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<td>800</td>
</tr>
<tr>
<td>13</td>
<td>3</td>
<td>4</td>
<td>60</td>
<td>2</td>
<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>700</td>
</tr>
<tr>
<td>14</td>
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<td>5</td>
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<td>1.5</td>
<td>1800</td>
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<td>500</td>
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<tr>
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<td>6</td>
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<td>2</td>
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<td>1800</td>
<td>0</td>
<td>100</td>
</tr>
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<td>7</td>
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<td>2</td>
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<td>0</td>
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</tr>
<tr>
<td>18</td>
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<td>60</td>
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<td>1800</td>
<td>0</td>
<td>800</td>
</tr>
<tr>
<td>19</td>
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<td>10</td>
<td>60</td>
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<td>1800</td>
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<td>450</td>
</tr>
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<td>13</td>
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<td>890</td>
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<td>1800</td>
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<td>840</td>
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<td>2</td>
<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>860</td>
</tr>
<tr>
<td>43</td>
<td>21</td>
<td>11</td>
<td>60</td>
<td>2</td>
<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>670</td>
</tr>
<tr>
<td>44</td>
<td>21</td>
<td>12</td>
<td>60</td>
<td>2</td>
<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>440</td>
</tr>
<tr>
<td>45</td>
<td>21</td>
<td>19</td>
<td>60</td>
<td>2</td>
<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>560</td>
</tr>
<tr>
<td>46</td>
<td>20</td>
<td>19</td>
<td>60</td>
<td>2</td>
<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>1200</td>
</tr>
<tr>
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<td>19</td>
<td>60</td>
<td>2</td>
<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>48</td>
<td>19</td>
<td>18</td>
<td>60</td>
<td>2</td>
<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>500</td>
</tr>
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<td>49</td>
<td>18</td>
<td>16</td>
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<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>270</td>
</tr>
<tr>
<td>50</td>
<td>18</td>
<td>17</td>
<td>60</td>
<td>2</td>
<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>640</td>
</tr>
<tr>
<td>51</td>
<td>9</td>
<td>21</td>
<td>60</td>
<td>2</td>
<td>1.5</td>
<td>1800</td>
<td>0</td>
<td>950</td>
</tr>
</tbody>
</table>
Table 4.8 Description of historical freeway incident trend file

<table>
<thead>
<tr>
<th>Link number</th>
<th>Incident minutes</th>
<th>Average number of lanes blocked</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>334</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>420</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>720</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>560</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>342</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>200</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>120</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>250</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>180</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>210</td>
<td>1</td>
</tr>
</tbody>
</table>
4.3.1.2 Results from analysis of the hypothetical network

The outputs from running the hypothetical network files above have been presented in Tables 4.9, 4.10 and 4.11. Table 4.9 shows the results based only on recurrent traffic congestion situations. Table 4.10 is for results based only on non recurrent traffic congestion situations and Table 4.11 is for results based on combined effects of both recurrent and non recurrent traffic congestions. Each output table has three columns. The first column shows the freeway link number. The second column shows the relative utility of the value of information and the third column shows the rank of a particular link. For example the link with the rank 1 has the highest utility value if motorists are given information on that link.

Figure 4.2 shows the graph of the profile of relative information values along the freeway.
### Table 4.9  
Results based on recurrent traffic congestion for hypothetical network

<table>
<thead>
<tr>
<th>Freeway link</th>
<th>Time savings</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8545.89</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>7582.78</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>6954.56</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>6244.44</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>6221.00</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>4506.44</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>4381.74</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>3003.26</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>2680</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>0.00</td>
<td>10</td>
</tr>
</tbody>
</table>

### Table 4.10  
Results based on non recurrent traffic congestion hypothetical network

<table>
<thead>
<tr>
<th>Freeway link</th>
<th>Time savings</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1111.00</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1074.72</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>979.10</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>598.20</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>512.34</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>419.41</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>285.21</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>275.96</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>180.94</td>
<td>9</td>
</tr>
<tr>
<td>1</td>
<td>0.00</td>
<td>10</td>
</tr>
</tbody>
</table>
Table 4.11  Results based on both recurrent and non recurrent traffic congestion hypothetical network

<table>
<thead>
<tr>
<th>Freeway link</th>
<th>Time savings</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5547.42</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>4994.07</td>
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<td>9</td>
<td>4340.07</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>3985.94</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>3846.68</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>3020.68</td>
<td>6</td>
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<td>6</td>
<td>2814.25</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>2006.89</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>1580.60</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>
Figure 4.2  Graph of profile of information utility along freeway in a hypothetical network
4.3.2 Model application to a real life network

The computer model developed (Information Location Advisor) has been applied to the Fairfax county transportation network which is located in the Northern Virginia region. A detailed section of the Fairfax county that has been used is shown in Figure 4.3. The network covers 9.5 miles of I-66 freeway section and neighboring arterials. The network representation consists of 42 nodes and 82 links. The input data have the same format as the hypothetical network. The results have been shown in Tables 4.12, 4.13 and 4.14.

Figure 4.4 shows a graph of the results for the Fairfax county network.
Figure 4.3 Fairfax county network (real life network)
Table 4.12  Results based on recurrent traffic congestion for Fairfax county network

<table>
<thead>
<tr>
<th>Freeway link</th>
<th>Time savings</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>9973.04</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>9102.32</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>5801.11</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>3235.44</td>
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</tr>
<tr>
<td>5</td>
<td>1932.17</td>
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<tr>
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<td>1622.56</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 4.13  Results based on non recurrent traffic congestion for Fairfax county network

<table>
<thead>
<tr>
<th>Freeway link</th>
<th>Time savings</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1922.65</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1128.74</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1032.15</td>
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<td>6</td>
<td>809.86</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>360.14</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>244.88</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>7</td>
</tr>
</tbody>
</table>
Table 4.14 Results based on both recurrent and non recurrent traffic congestion for Fairfax county network

<table>
<thead>
<tr>
<th>Freeway link</th>
<th>Time savings</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>6752.88</td>
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</tr>
<tr>
<td>2</td>
<td>5874.25</td>
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<tr>
<td>6</td>
<td>3804.61</td>
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<tr>
<td>4</td>
<td>2392.76</td>
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</tr>
<tr>
<td>5</td>
<td>1303.36</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>986.34</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>7</td>
</tr>
</tbody>
</table>
Figure 4.4  Graph of profile of information utility along I-66 in Fairfax county network
In both the cases of the hypothetical network and the real life network, the graphs indicate that for travel time information presented to motorists on a particular freeway link (indicated as link on graph) the corresponding travel time savings (on the vertical axis) is the total relative travel time savings of all the motorists. The differences in the relative travel time savings is influenced by the many factors that have been considered in the methodology. These include the incident history of the freeway links, the historical freeway link volume, the availability of alternate routes to the freeway link and the average travel times on the alternate routes. Typically from Figure 4.2, link 1 has a higher utility value than any of the other freeway links. This is probably due to the fact that link 1 has more alternate routes associated with it than the other links or has alternate routes that have lower average traffic flows than the other links, or have high link volume since these factors will enable diversion of more vehicles from the freeway to the alternate arterial routes and hence higher travel time savings. The high freeway link volume factor however seems to be more compelling, since links with high freeway link volumes generally show high utility values as shown in the figures and the tables. It must however be noted that the incident minutes associated with each link also plays a significant role in the relative utility values for the non recurrent congestion situations.
CHAPTER V
VALIDATION OF THE INFORMATION LOCATION ADVISOR

The Information Location Advisor (ILA) that has been developed and described in the previous chapter uses historical traffic data as an input, as such it has been deemed necessary to validate the model using real time traffic simulations. The simulation model used has been developed with the SIMSCRIPT II.5 programming language and the SIMSCRIPT II.5 simulation modeling approach (CACI Products 1987, CACI Products 1988).

In the subsequent sections, a general description of simulation modeling approach has been briefly described. This is followed by the description of the validation simulation model logic and the results of the validation.

5.1 Simulation Modeling

Simulation is the operation of a model that represents the dynamic behavior of a system. The model is amenable to manipulation that would be impossible, too expensive or impractical to perform on the system it portrays. The operation of the model can be studied and from it properties concerning the behavior of the actual system can be inferred.
Simulation is an effective way of pretesting systems, plans or policies before developing expensive prototypes and actual implementation. Using computer based simulation, it is possible to trace out in detail the consequences and implications of a proposed course of action. Simulation is an efficient tool for modeling problems which may not be solved analytically or problems in which there is no fixed relationship among the components from time to time. The flexibility of the simulation model can be utilized to effectively change the input parameters anytime during the simulation. For the above reasons, simulation approach is adopted in this aspect of the research project.

5.1.1 Structure of a Simulation Model

Simulation models exhibit many common properties. Every model has the following properties:

- A mechanism for representing arrivals of new objects
- The representation of what happens to the objects within the modeled system
- A mechanism for terminating the simulation

The arrival of new objects into the system from the external world is usually independent of what happens within the system. This process can be characterized by describing the number of objects that arrive simultaneously and specifying the time between arrivals. The primary focus of the modeling effort is the representation of what happens to the objects within the modeled system. Finally, a model must be provided with a means of termination. There are two methods of termination. The first is the planned termination
method, in which the termination is scheduled for a definite simulation time regardless of what else might be happening in the model. The second method is to allow everything in the model to come to rest.

5.2 Building Simulation Models in SIMSCRIPT II.5

SIMSCRIPT is a high level, powerful, free-form, English like simulation language. It is used because of its versatility and user-friendliness. SIMSCRIPT was first developed by Harry Markowitz and it has undergone various structural changes to make it more useful and easy to use. The state of the system here is defined by entities, their associated properties or attributes and by logical grouping of entities. The dynamic structure of the system is described by defining the changes that occur at event times.

In SIMSCRIPT Process concept is the primary dynamic object and the Resource is the passive object which caters to the Process. The process and the Resource are described below.

The Process

A process represents an object and the sequence of actions it experiences throughout its life in the model. There may be many instances or copies of a process in a simulation. There may also be many different processes in a model. A process object enters a model at an explicit simulated time, its creation time and interacts either implicitly or explicitly with other processes in the system. At each activation of the process routine, it may execute statements representing the changes to the system.
The Resource

Resources are the passive elements of a model. A resource is used to model an object which is required by the process objects. If the resource is not available when required, the process object is placed in a queue or waiting line and made to wait until the resource becomes available. In this project, the resource concept would not be used as the model does not involve any queuing process.

5.2.1 SIMSCRIPT-Program Architecture

A SIMSCRIPT II.5 program consists of three primary elements.

- A preamble giving a static description of each modeling element
- A main program where execution begins
- A process routine for each process declared in the preamble

Preamble

The first section of any SIMSCRIPT model is the preamble. It is purely declarative and it does not include any executable statements. All the modeling elements must be named in the preamble.

Main

Execution of a SIMSCRIPT program begins with the first statement in the main program. Several necessary steps are taken in the Main program for a simulation. SIMSCRIPT requires that something be awaiting execution before a simulation
commences. This is done by activating initial processes in the Main. A simulation begins when the control passes to a system supplied timing routine. This is done by executing the Start Simulation statement. Any statement following this will not be executed until the simulation has terminated. At this point final reports can be produced and a new simulation could be run.

*Timing Routine*

The timing routine is at the heart of discrete-event simulation. From a programming perspective, this is the routine that ties the entire collection of processes together. Processes must be on the pending list prior to entry into this routine or the simulation will terminate immediately. It is natural to assume that the execution of one process will activate other processes and thus perpetuate this sequence for sometime. Termination will occur either for the algorithmic reason or because of a stop statement.

*Process Routines*

Each process declared in the program preamble must be further described by a process routine. From a programming point of view, the process routine embodies the logic description of a process, telling what the process object does under all circumstances. Information pertinent to each process-instance is stored with the process notice.

*Entities and Sets*

Entities are modeled as either permanent or temporary. Permanent entity is used when the number is not likely to change during the simulation run. A temporary entity is used when the number is likely to change. Sets contain a group of temporary entities and it is owned by a permanent entity.
**Graphical Interface and Animation**

SIMSCRIPT II.5 has the capability of state or dynamic presentation of graphics, interactive graphics and animated displays. This is done with the help of SIMSGRAPHICS, an extension of SIMSCRIPT II.5. Typical applications have been described below.

**Data Representation**

Histogram, pie charts, X-Y plots, and other graphics can be generated to display numerical or statistical information.

**Model Representation**

Animated graphics can represent the system under simulation evolve as the simulation progresses.

**Run Configuration**

Simulation experiments start from some initial conditions, which can be easily set by manipulating a graphical representation of the system. Interactive reconfiguration at run-time can reduce the iterations needed to achieve reconfiguration at run-time and can reduce the iterations needed to achieve stable results. This makes the simulation progress more general. Asynchronous input allows the user to alter the scenario as it runs.
**Presentation Graphics**

Smart icons such as clocks, dials and meters allow us to view changes in speed, altitude or queue size as the simulation runs. Histograms, pie charts, line graphs and trace plots concisely display the results of the simulation.

**Graphics for Animation**

Creating detailed graphic shapes is as easy as drawing the shape on the screen with a mouse. Once created, these shapes can be tied to SIMSCRIPT entities. An entity's icon is automatically animated and updated to represent its current state. Animated entities are defined as dynamic graphic entities in the preamble.

**Forms**

Forms can be created with the graphics editor to manage user interaction. This feature allows the user to easily create elegant user interface.

In the simulation model used in this research, the animation component has not been considered relevant and hence it is not part of the model. Traffic stream models however play an important role in traffic simulations. Before proceeding to discuss the important aspects of the validation simulation model an overview of some traffic flow models have been presented.
5.3 Traffic Flow Models

Traffic flow models describe interactions among the transportation system elements, that is the driver, the vehicle and the road. Traffic flow could be modeled in terms of three fundamental traffic variables: flow, density and speed. The modeling of traffic in terms of these variables requires three equations (Ross 1988):

- The general equation of traffic stream where flow is the product of speed and density
- The equation of conservation of vehicles where the difference between the number of vehicles entering a link and that leaving it during a given time interval corresponds to the change in the number of vehicles traveling on the link (Lighthill and Whitham 1955); and
- The relationship between speed and density or between acceleration-density gradient.

A traffic flow model is classified as microscopic or macroscopic based on the level of flow description. On the microscopic level, traffic is described in terms of individual vehicle behavior. This method of modeling is also called the car-following modeling represented by response-stimulus relationships. The macroscopic approach on the other hand entails the description of traffic by the average behavior of a traffic stream in a local region. Macroscopic modeling technique can be further divided into traffic stream modeling and continuum modeling depending on the order of the governing equations. Traffic stream models use speed-density relationship and continuum models employ acceleration-density gradient relationship respectively to represent average behavior of the traffic stream. Traffic stream models and car-following models have been summarized in the following discussions.
5.3.1 Traffic Stream Models

Early research was focused on the development of flow-density-speed relationships based on the observation of empirical data. The basic structure of the model is defined by the first-order speed-density relationship:

\[ u = u_e(k) \]  \hspace{1cm} [5.1]

where:

\( u_e(k) \) is the equilibrium relationship between speed and density.

Greenshields (1934), one of the early researchers of traffic flow, proposed a linear relationship between flow and speed. This model results in familiar parabola-shaped relationships between flow and density as well as between speed and flow:

\[ u = u_f (1 - k/k_j) \]  \hspace{1cm} [5.2]

where:

\( u_f \) = free flow speed at which traffic is moving freely without interacting with other vehicles, and

\( k_j \) = jam density at which concentration of vehicles is maximum

Greenberg (1959) developed a logarithmic speed-density model, assuming that the traffic flow was equivalent to one-dimensional fluid state. It has been discovered that Greenberg's model could be related to one of the car-following models. The Greenberg model is given as:
\[ u = u_m \ln(k_j/k) \]  \hspace{1cm} \text{(5.3)}

where:

\[ u_m = \text{speed at which flow reaches capacity} \]

*Underwood (1961)* proposed another version of the traffic stream model:

\[ u = u_f e^{\left( \frac{k}{k_m} \right)} \]  \hspace{1cm} \text{(5.4)}

where:

\[ k_m = \text{density at which flow reaches capacity} \]

*Drew (1967)* introduced an additional parameter \( n \) and proposed a family of traffic stream models:

\[ U = U_f \left[ 1 - \left( \frac{k}{k_j} \right)^{n+1} \right] \]  \hspace{1cm} \text{(5.5)}

where:

\[ n=1: \quad \text{Greenshields' linear model;} \]

\[ n = -1: \quad \text{exponential model;} \]

\[ n = 0: \quad \text{parabolic model} \]
Several other traffic flow models exist besides the ones discussed. Some of the additional models can be found in (Gerlough and Huber 1975; May 1990; McShane and Roess 1990). Figure 5.1 shows various speed-density hypotheses of traffic stream models.
Figure 5.1 Speed-density hypothesis (source: Gerlough and Huber 1975)
5.3.2 Car Following Models

The study on the human behavior of car following started in the 1950s, about 20 years after the first traffic stream model was introduced. The manual car-following theory assumed that the individual vehicle followed the vehicle ahead according to a certain headway control rule. A typical car following model is:

\[ \text{response} = \text{sensitivity} \times \text{stimulus} \]  \hspace{1cm} [5.6]

where the response is the acceleration or deceleration of a vehicle in question, the stimulus involves the relative velocity between the vehicle in question and the vehicle ahead, the relative spacing between them, and the absolute velocity level. The sensitivity includes the driver's sensitivity and other factors like mechanical response delay.

Pipes (1953) initiated the development of the car following model by relating the velocity of a vehicle in question to the safe space headway. The minimum safe distance between the lead and the following was assumed equal the length of a vehicle every ten miles per hour of speed of the following car.

\[ d_m = \left( \frac{\dot{X}_{n+1}}{1.47 \times 10} \right) + l_n \]  \hspace{1cm} [5.7]

where \( l_n \) is the length of a vehicle ahead.
Forbes (1958) improved the Pipes's safe distance model by incorporating driver's perception-reaction time necessary for perceiving the need to decelerate and applying the brakes. He proposed a time headway model which is given as:

$$h_m = \frac{t_n}{X_{n+1}} + \Delta t$$  \hspace{1cm} [5.8]

where $\Delta t$ is the driver's perception reaction time.

General Motors (1959) launched extensive field studies and developed a series of modern forms of car-following models. The first model has a constant sensitivity term as follows:

$$\dot{X}_{n+1}(t + \Delta t) = \alpha \left[ \dot{X}_n(t) - \dot{X}_{n+1}(t) \right]$$  \hspace{1cm} [5.9]

where $\alpha$ is a constant sensitivity.

In the second model the space headway was added to the sensitivity term. The response of the following car was thus assumed to be inversely proportional to the space headway. The dimension of the constant sensitivity term became distance per time, i.e. velocity.

$$\ddot{X}_{n+1}(t + \Delta t) = \frac{\alpha}{X_n(t) - X_{n+1}(t)} \left[ \dot{X}_n(t) - \dot{X}_{n+1}(t) \right]$$  \hspace{1cm} [5.10]

where $\alpha$ is the velocity of the vehicle in question (following vehicle).
The above second model was further refined. The driver of the following car would be more sensitive to the relative speed of the lead and the following car as the speed of the following car increases. In this model, the constant is dimensionless.

\[
\ddot{X}_{n+1}(t + \Delta t) = \alpha \left[ \frac{\dot{X}_{n+1}(t + \Delta t)}{X_n(t) - X_{n+1}(t)} \right] \left[ \dot{X}_n(t) - \dot{X}_{n+1}(t) \right] \quad [5.11]
\]

where \( \alpha \) is constant.

Further generalizations of the sensitivity components produced a final model of the series with the following sensitivity components.

\[
\ddot{X}_{n+1}(t + \Delta t) = \alpha_{i,m} \left[ \frac{\dot{X}_{n+1}(t + \Delta t)}{X_n(t) - X_{n+1}(t)} \right]^m \left[ X_n(t) - \dot{X}_{n+1}(t) \right] \quad [5.12]
\]

It can be shown that the car-following model given above in Equation 5.12 translates to the Greensberg's macroscopic traffic stream model (Equation 5.3) for values of \( l=0 \) and \( m=2 \).
5.3.3 Proposed Generalized form of Greenshield’s Model

(Helinga and Van Aerde 1994b) proposed a generalized form of the Greenshield’s model, which is given in Equation 5.13 below.

\[ D = \left[ C_1 + \frac{C_2}{S_f - S} + C_3 S \right]^{-1} \quad [5.13] \]

Based on the general form, the speed-flow relationship can be expressed as:

\[ (1 - VC_3)S^2 + \left(-VC_1 + V C_3 S_f - S_f\right)S + \left(V C_2 + V C_1 S_f\right) = 0 \quad [5.14] \]

\[ C_1 = k C_2 \]

\[ C_2 = \frac{1}{D \left( k + S_f^{-1}\right)} \]

\[ C_3 = \left[-C_1 + \frac{S_c}{V_c} + \frac{C_2}{(S_f - S_c)}\right]S_c^{-1} \]

\[ k = \frac{2S_c - S_f}{(S_f - S_c)^2} \]

where:

\[ D = \text{density (number of vehicles per mile per lane)} \]

\[ S = \text{speed (miles per hour)} \]

\[ S_f = \text{free speed (miles per hour)} \]
\[ V_c = \text{flow at capacity} \]

\[ S_c = \text{speed at capacity (miles per hour)} \]

\[ V = \text{flow (vehicles per hour)} \]

The above generalized form of the Greenshield’s model shows deviations from the standard parabolic speed-flow curve and results in a speed-density relationship that is not only non-linear, but also follows the common S-shape. This is illustrated in Figure 5.2. The proposed curve can be noted to produce a jam density different from four times the ratio of the capacity and free speed which is characteristic of the Greenshield’s linear model.
Figure 5.2 Generalized and the standard Greenshield's model
5.4 Development of the Validation Simulation Model

The simulation model developed in this research is mesoscopic in nature. In other words it is both microscopic and macroscopic in nature. Vehicles generated in the model are moved through the model as individual entities until they exit the model. However, the speed of a vehicle is determined in the model using a macroscopic approach.

The simulation model used for the validation has several processes and routines which perform several different functions. The simulation was carried out using the hypothetical network (Figure 4.1) and the real life network (Figure 4.3). These networks have been used so that the results produced by the simulation models could easily be validated against the results produced by the Information Location Advisor. Measurements and collection of any statistics during the simulation begins an hour after the simulation is actuated. This is to ensure that the system gets into a kind of a steady state situation. The simulation was carried out on segment by segment basis which is similar to the analysis of a freeway segment using the Information Location Advisor. Figure 5.3 shows a typical segment. For a freeway section in the direction E-W, the simulation generates vehicles on all the links F2, L1, L2, L3, R1, R2 and R3 at a rate equal to the historical hourly link volumes. Most of the vehicles generated on F2 have been assumed to be coming from F1. Every vehicle on link F1 seeks to travel on the freeway and as such wishes to continue on the link F2. However before exiting link F1, the motorist has real time information on the prevailing travel conditions on link F2 and on other alternate routes to link F2 which are routes formed by links L1, L2 and L3 and by links R1, R2 and R3. The simulation model assumes that every individual driver behaves rationally and
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would want to use any of the alternate routes to link F2 in lieu of F2, if he/she could save an assumed threshold value of more than 3 minutes during incidents. However, the true choice of a threshold value should be determined by the traffic management team of the particular jurisdiction. A typical method of estimating such values is to interview motorists to know how much travel time savings on the average will make them switch routes.

The components of the model include a Preamble and Main as is typical of all simulation models built in the SIMSCRIPT II.5 language. Some of the other major processes and routines in the simulation model include Arrivals Generators, Travel time routine, Distance routine and Stop controller.

The Preamble defines all the processes and global variables used in the model development. The Main is where all data input takes place and all the processes activated for the simulation to begin. The Arrival Generators generate vehicles on the links of the segment being analyzed at constant time intervals. As mentioned earlier, traffic is generated on each link based on historical hourly volumes. Therefore the constant headway between generated vehicles is determined within the model such that the historical hourly volume of vehicles is generated after each one hour of simulation time.

The travel time routine which incorporates a function to simulate variable message signs is the most important component of the model. Travel time estimation in the simulation model has been described in some details below. The Stop controller process outputs the relevant statistics at the end time of the simulation which has been specified at the beginning of the simulation.
Figure 5.3 Typical simulated network
5.4.1 Simulation Travel Time Estimations

As discussed earlier, the decision by a motorist to continue downstream onto another freeway link or to divert onto alternative routes formed by arterial links is based on the travel time information presented to the motorist on an upstream link. This in turn is a function of the velocity of the vehicles in the model.

Several traffic stream models have been discussed in Section 5.3.1. Vehicle's travel time within the simulation model has been based on the proposed generalized form of Greenshield's macroscopic model (Helinga and Van Aerde, 1994b).

The velocity of all vehicles in the model is computed every quarter of a second using the proposed generalized form of the Greenshield's model illustrated in Equations 5.13 and 5.14. The use of the generalized model requires the following parameters: jam density, speed at capacity, free speed and capacity. The same capacity values that have been used with the Information Location Advisor have been used in the simulation. Essentially the link capacities can be estimated by adjusting the ideal link capacity for traffic signals, incidents, geometric features to yield the actual net value. The jam density has been estimated using the original Greenshield's model which gives jam density as the ratio of four times the capacity flow and the free speed. The free speeds just as in the case of the Information Location Advisor have been set to be the link speed limits. At any time in the model, the link density is computed from the link length and the number of vehicles on the link which is computed as the difference between the number of vehicles that entered and exited a link. The values of k, C1, C2 and C3 above (Equation 5.13) can then be computed hence the vehicle's velocity. If the entry of a vehicle onto a link will
cause the link density to equal or exceed the jam density, it is held in a queue until it could enter on to the link. The delay in the queue adds to the vehicles total travel time.

Within the simulation model, there is another routine which computes the distance of every vehicle using the estimated vehicle velocities and the simulation clock. Distance traveled by each vehicle in the model is computed every quarter of a second just as the velocities. Any vehicle generated onto a link gets terminated after the total distance traveled by the vehicle (as computed from the distance routine) is the same as the length of the link it is traversing. The entry time of the vehicle into the network and the exit time of the vehicle out of the network get stamped. The difference between the link entry time and link exit time gives the link travel time of a vehicle.

5.4.2 Travel Time Smoothening

The travel time data that describes actual network conditions and presented to motorists in real time to enable them make their route choice decisions is the exponentially smoothed average link travel time of all vehicles that have traversed that link. The travel time smoothening approach used here is similar to the one used in the Integration simulation model (Van Aerde 1994). It is assumed at the time that travel time information is presented to a motorist that, such travel time conditions will remain in effect and is what the motorist will experience if he chooses that link at the time the information is delivered to him/her. Each time a vehicle exits a link (i.e. finishes traversing the link, including all delay at the downstream node), the travel time for that link is updated using Equation 5.12 below.
\[ t_m = \alpha \times t_v + (1-\alpha) \times t \]  \hspace{1cm} [5.12]

where:

\( t_m \) = modified link travel time
\( \alpha \) = smoothing factor
\( t_v \) = total time taken by the vehicle to traverse and exit the link
\( t \) = smoothed link travel time prior to incorporating the travel time of the vehicle

A check is made every second to determine if a vehicle has spent more time on a link than the average link travel time is updated using Equation. The link travel time continues to be updated in the usual manner when the vehicle exits the link.

\[ t_m = \beta \times t_d + (1-\beta) \times t \]  \hspace{1cm} [5.13]

where:

\( t_m \) and \( t \) are as defined before
\( \beta \) = smoothing factor (different from \( \alpha \))
\( t_d \) = travel time experienced so far by the vehicle

Values of \( \alpha = 0.2 \) and \( \beta = 0.10 \) have been used as recommended by (Van Aerde, 1994)

If no vehicles are on the link, then the current link travel time estimate is updated with the free-flow travel time through the same exponential smoothing process described above.
5.4.3 Simulated Scenarios

Both recurrent and non-recurrent congestion situations have been simulated. The simulations have been performed on both the hypothetical network and real (Fairfax county) network. In each case a base scenario was run in which motorists receive no information on network conditions and then another scenario in which motorists receive travel time information on travel routes. The travel time savings were calculated as the difference between the case when motorists receive no information and when they receive information.

With the recurrent congestion scenario, peak hour traffic flow conditions have been simulated for about four hours with statistics collected on all those vehicles generated over one hour period (between the second and the third hour). This is consistent with the use of the Information Location Advisor in which results were collected over one hour period for peak hour flow conditions. As discussed in the previous section, motorists are continuously supplied with travel time information to enable them choose the best routes.

The features of the non-recurrent congestion simulation also follows the same criteria as with the conditions used with the Information Location Advisor. The average capacity of the roadway blocked during incidents was simulated as the reduction in the freeway capacity, assuming the influence section of the capacity as a one mile region. The same average reduction in capacity which has been obtained from the one year historical incident database for Fairfax county and used with the Information Location Advisor has
been used in this case too. In the case of the hypothetical network, the assumed values used with the Information Location Advisor has been used in the simulation.

5.5 Comparison of Simulation and ILA Results

The results from the simulation model have been tabulated with the results obtained from ILA as shown in Tables 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6. Also shown in the tables are the differences in the ILA and simulation results (ILA-simulation results) as a percentage of the ILA results. It must be noted however that the combined recurrent and non recurrent congestion based results of Table 5.3 has been derived as the sum of the 40 percent weighting and the 60 percent weighting of the recurrent congestion based results of Table 5.1 and non recurrent congestion based results of Table 5.2 respectively. (See Equation 3.7). A similar approach has been used for the derivation of Table 5.6 for the real network. Graphs comparing the results have also been shown in Figures 5.4, 5.5 and 5.6.

Table 5.1 which compares the recurrent congestion based results for the hypothetical network shows differences in travel time savings ranging from about as high as 1000 minutes for link number 7 to about 140 minutes for link number 6. These differences correspond to percentage changes varying from 3.2 percent to 16.7 percent. The non recurrent congestion based results for the hypothetical network shown in Table 5.2 also indicates percentage differences in travel time savings varying from about 1.5 percent to about 7.5 percent.
Table 5.4 compares the recurrent congestion based results for the real life network. The differences in travel time savings vary from about as high as 730 minutes for link number 3 to about 100 minutes for link number 1. The differences in travel time savings correspond to a range of about 3.7 percent to about 11.7 percent. Also, the differences in travel time savings range from about 2.2 percent to about 5.6 percent for the non recurrent congestion based results shown in Table 5.5.

In general, the differences in the results using the ILA and the simulation results are fairly high. Those links which show very big differences in travel time savings for the two methods (ILA and simulation) such as link number 7 for the hypothetical network and link number 3 for the real network are probably those links with more alternate routes or traffic diversions as compared to the other links. Such factors are likely to induce fluctuations in vehicle travel times. Another factor which could influence the differences in the travel time savings is the threshold value of 3 minutes that has been used. A different value instead of the 3 minutes could have produced different results. Despite the big differences in the travel time savings, what is noteworthy about the simulation results is that they show approximately the same relative utility of information by location as produced by the ILA. It is however important that an engineer uses his/her judgment when considering the choice between two sites for locating information, if those two locations have their information utilities from the ILA reasonably close, since there is the likelihood that another method could have switched the ranks of those two positions.
Table 5.1 Comparison of recurrent congestion based results for Hypothetical network

<table>
<thead>
<tr>
<th>Freeway link</th>
<th>ILA time savings (min.)</th>
<th>Simulation time savings (min.)</th>
<th>Percent difference</th>
<th>Rank</th>
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Table 5.2 Comparison of non recurrent congestion based results for Hypothetical network

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<th>Freeway link</th>
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<th>Simulation time savings (min.)</th>
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Table 5.3 Comparison of both recurrent and non recurrent congestion based results for Hypothetical network

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Table 5.4 Comparison of recurrent congestion based results for Fairfax county

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Table 5.5 Comparison of non recurrent congestion based results for Fairfax county

<table>
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<th>Freeway link</th>
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Table 5.6 Comparison of combined recurrent and non recurrent congestion based results for Fairfax county

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Figure 5.4 Comparison of recurrent congestion based results for a hypothetical network
Figure 5.5 Comparison of non recurrent congestion based results for Hypothetical network
Figure 5.6 Comparison of both recurrent and non recurrent congestion based results for Hypothetical network
Figure 5.7 Comparison of recurrent congestion based results for Fairfax county network
Figure 5.8 Comparison of non recurrent congestion based results for Fairfax county network
Figure 5.9 Comparison of combined recurrent and non recurrent congestion based results for Fairfax county network
CHAPTER VI
CONCLUSION

6.1 Summary of Research

The ever increasing cost of traffic congestion which is a commonplace in most of the world's cities today have had transportation professionals working relentlessly to find solutions to mitigate the problem. For several years, the efforts of the professionals which have been mostly concentrated on employing traditional congestion management methods could not help alleviate the problem. This is primarily because the traditional congestion management strategies which involve both traffic demand and supply management can no longer keep up with the pace of congestion growth. However, recent advancements in computers and communication systems have resulted in the development of an integrated technology known as Intelligent Transportation Systems (ITS). This technology is believed to be capable of providing a robust and lasting solution to the traffic congestion problem. The main components of the Intelligent Transportation Systems technology include Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Advanced Vehicle Control Systems (AVCS), Commercial Vehicle Operations (CVO) and Advanced Public Transportation Systems (APTS).

ITS research developments particularly in the areas of ATMS and ATIS have resulted in the development of dynamic route guidance systems. Among other things, these systems are capable of providing real time information on traffic conditions to motorists in order
to guide them from their origins to destinations. Nonetheless, the efficacy of the dynamic route guidance systems depend heavily on the effectiveness and efficiency of enroute communication systems. This in turn depends on the location of the information systems which could be in the form of variable message signs, beacons etc. While it is generally acknowledged that the more frequent information is presented to motorists, the more efficient and effective will be the dynamic route guidance systems, financial constraints cannot permit indiscriminate location of information devices on the network. Thus the objective of this research has been to develop a system which could help transportation professionals in making decisions as to the best location of information systems to achieve the best results. The research focused on ranking sites (links) along freeway corridors according to usefulness of information presented on them. The objective of the research has been achieved by carrying out the following major tasks:

- Development of a methodology for estimating information utility at potential information location sites under recurrent traffic congestion situations
- Development of a methodology for estimating information utility at potential information location sites under non-recurrent congestion situations
- Development of a computer model based on the methodology for estimating information utility at potential information sites under recurrent congestion situations
- Development of a computer model based on the methodology for estimating information utility at potential information sites under non-recurrent congestion situations
- Integration of the recurrent and non recurrent congestion based computer models
- Validation of the computer models using simulation methods
The development of the methodologies have been based on the fact that motorists behave rationally and thus will prefer to divert from freeway links on to alternate arterials that offer reasonable travel time savings than traveling on the freeway links (user equilibrium route choices). The transportation planner then utilizes total system travel time savings in evaluating the benefits of information systems.

The computer models based on the methodologies have been developed using the C++ language. However, because the methodologies, hence the computer models have been based on historical traffic data, the computer models have been validated using simulation models developed with the SIMSCRIPT II.5 simulation language. The simulation results produced reasonably consistent results as the computer models on their application to a hypothetical and real life traffic networks.

Several factors influence the utility of providing information on a particular freeway link. These combination of factors include traffic volumes on alternate arterial routes to the freeway link, the number of alternate routes to the freeway link especially under recurrent traffic congestion conditions, link lengths, volume of traffic on the freeway link and incident history in the case of non recurrent congestions. With the particular networks investigated in this research however, volume of traffic on the freeway link appears to be the most influencing factor, since freeway links with relatively high traffic volumes tend to have relatively high utility values as shown by the results. This is probably due to the small size nature of the networks used, hence as a result all the freeway links tend to have only one or two alternate routes and the traffic volumes on the arterial links also do
not differ significantly. The freeway link volumes therefore become the dominating factor in influencing the information utilities.

6.2 Further Research

The research methodology in this work has been based on the fact that motorists get diverted based on the point diversion strategy. This implies that motorists get diverted from the exit ramp immediately preceding a congested link, to the entry ramp immediately following the congested link. This strategy may not be the most appropriate under all types of congested conditions. A corridor wide strategy which attempts to divert motorists from a few exits upstream of a congested link to a few exits downstream of the congested link might be more appropriate under some conditions. Thus a research in that direction is worth pursuing.

Also in the event of a very major incident that causes several freeway links to be closed for long periods of time, an Inter-freeway diversion strategy to divert traffic from one freeway to another, may be appropriate. Although this might not be a frequent occurrence, a study of empirical data relating to such occurrences might help further improve the results of this research by assigning appropriate weighting factors to utility of information values.

One other major issue in this research is the assumption that all motorists behave rationally and so a 100 percent compliance level has been assumed in the models. This might not necessarily be the situation. Some conservative motorists under all conditions
will prefer to go on the freeway unless the freeway is entirely closed. As such a research which calls for different compliance levels will be useful in addressing this subject.
REFERENCES


APPENDIX-PARTIAL CODE FOR THE ILA

#include <stdio.h>
#include <ctype.h>
#define NONE 120
#define TITLE1 "Results based on non_recurrent traffic congestion"
#define TITLE2 "Freeway link Time savings Rank"
#include <math.h>

//input files are arterial.dat, freeway.dat, incident.dat, output
typedef struct {
  float num,in_i_node,final_node,free_speed,no_of_lanes,link_length,lane_capacity,
    signal, link_vol,fin_node_of_dwn_stream,link_time; }data;

int mat_no, mat_entry,i,j,k,index, rut_num,iterator;
float a_node_one, a_node_two, a_node_three, a_one_node_one, reserv[100][3],
  a_one_node_two, a_one_node_three, d_one_node_one, d_one_node_two,
  d_one_node_three, c_one_node_one, c_one_node_two, c_one_node_three, timer[100],
  b_one_node_one, b_one_node_two, b_one_node_three, save1, save2, timeout[100];
void recur_output(void), A_one_first(void), B_first(void), Eliminator(void),
  A_one_second(void), A_one_third(void), C_first(void), D_first(void),
  A_two_first(void), A_two_second(void), A_two_third(void), C_second(void),
  D_second(void), A_three_first(void), A_three_second(void),
  A_three_third(void), C_third(void), D_third(void);

float a_two_one_node, a_two_node_two, a_two_node_three, d_two_node_one,
  d_two_node_two, d_two_node_three, c_two_node_one, c_two_node_two, c_two_node_three,
  b_two_node_one, b_two_node_two, b_two_node_three, base_travel_time,
  lowest_arterial_travel_time, time_one, time_two, time_three,
  ratio_one, ratio_two, ratio_three, ratio_four, measure, total_inc;

float a_three_one_node, a_three_node_two, a_three_node_three, d_three_node_one,
  d_three_node_two, d_three_node_three, c_three_node_one, c_three_node_two,
  c_three_node_three, b_three_node_one, b_three_node_two, b_three_node_three,
  new_time, time_total_one, time_total_two, time_total_three;

float A[3][12], A1[3][12], B[3][12], C[3][12], D[3][12];
float A2[3][12], B2[3][12], C2[3][12], D2[3][12], Route[26][18];
float A3[3][12], B3[3][12], C3[3][12], D3[3][12], store[18];

/* from initial freeway node say A, there are three possible links that come out A(1), A(2) or A(3).*/
/*XTIME GIVES THE AVERAGE TRAVEL TIME ON A LINK*/
/*X1...GIVES THE LINK NUMBER OF AN ARTERIAL LINK*/

float freew_link[100];/*stores the link numbers of freeways to be considered*/
int fre_link, fre_exam, arterial_counter, arterial_no_of_lines, counter=0;
//stores information on link(nodes, capacity, travel time etc).
void matrix(void);
void group_a_one(void);
void group_b_one(void);
void group_c_one(void);
void group_d_one(void);

void group_a_two(void);
void group_b_two(void);
void group_c_two(void);
void group_d_two(void);

void group_a_three(void);
void group_b_three(void);
void group_c_three(void);
void group_d_three(void);
void Rank(void);
void recur_out(void);
void Traffic_assignment(void);
void Rat_one(void);
void Rat_two(void);
void Rat_three(void);
void recur_out(void);

char out_rec[NONE], input[NONE], incident[NONE], master[NONE], dummy[NONE], comb[NONE];
char ch, trash[NONE], freeway_file[NONE], arterial_file[NONE], out_non_rec[NONE];
FILE *f_freeway, *f_arterial, *f_out_rec, *f_master, *f_incident, *f_out_error, *f_out_non_rec;
float vee_to_cce_ratio_fwy, vee_to_cce_ratio_art, free_speed_travel_time,
fin_node_of_dwn_strm_link, arterial_free_speed_travel_time,
free_link_info[12], arterial_link_info[12], vee_to_cce_ratio_arterial;
data freeway, arterial;

main()

{ // start of main
void Route_generator_two(void);
void freew_func(i(void);
void file_finder(void);
void arterial_line_counter(void);
void Route_generator_one(void);
void Route_arranger(void);
void Terminator(void);
void Terminator_two(void);
void order(void);
void Travel_time(void);
file_finder();   //find the input and outfiles
arterial_line_counter(); // count the number of lines in arterial data file
//freew_func();
//Route_generator_one();
//if (A[0][2]==0&&A[1][2]==0&&A[2][2]==0) { recur_out; } else

//Route_arranger();
//Terminator();
//Terminator_two();
//order();
//Travel_time();
//Rank();
//Traffic_assignment();

while(counter<fre_examin)

{
    base_travel_time=0;
    iterator=0;
    new_time=0;
    measure=0;
    freew_func();
    A[0][2]=0; A[1][2]=0; A[2][2]=0;
    Route_generator_one();

    {timeout[t]=0;
     freew_link(t)=free_link_info[0];
     t=t+1;
    }
    else {
        Route_arranger();
        Terminator();
        Terminator_two();
        order();
        Travel_time();

    }
// printf("counter=%d\n and  fre_examin=%d\n", counter, fre_examin);
} // end of while

// printf("free_speed_travel_time=%d\n",free_speed_travel_time);
// Route_generator();
// printf("arterial lines=%d",arterial_no_of_lines);
void file_finder(void)
{
    printf("Enter the master input file name\n");
    gets(master);

    if ((f_master=fopen(master, "r")) == NULL) /*fetching master file which
        contains all other input files and number of freeway links in the file
        to be examined*/
    { printf(" master file does\n");
        printf("not exist or is in wrong directory\n"); } /*exit(); */
    fgets(dummy, NONE, f_master); /*read and throw away title of input file*/
    fscan(f_master, "\%[^\n]", freway_file);
    ch=getc(f_master);
    //fgets(input, NONE, f_master); /*pick name of network file*/
    fscan(f_master, "\%[^\n]", arterial_file);
    ch=getc(f_master);
    fscan(f_master, "\%[^\n]", incident);
    ch=getc(f_master);
    //fgets(incident, NONE, f_master); /* pick name of incident history file*/
    fscan(f_master, "\%[^\n]", out_rec);
    /*pick name of output file*/
    ch=getc(f_master);
    fscan(f_master, "\%[^\n]", out_non_rec);
    /*pick name of output file for non recurrent condition*/
    ch=getc(f_master);
    fscan(f_master, "\%[^\n]", comb);
    /*pick name of output file for non recurrent condition*/
    ch=getc(f_master);
    fscan(f_master, "\%d", &fre_link); /*pick number of freeway links*/
} // end of main
printf("fre_link=%d\n",fre_link);
fscanf(f_master,"%d",&fre_examin); /*pick number of freeway link to be examined*/
printf("fre_examin=%d\n",fre_examin);
fclose(f_master);

/*
 printf("\%s\n", dummy);
 printf("\%s\n", freeway_file);
 printf("\%s\n", arterial_file);
 printf("\%s\n", incident);
 printf("\%s\n", output);
 printf("\%s\n", fre_link);
 printf("\%s\n", fre_examin); */

/*
 fgets(trash, NONE, f_input);
 printf("\%s\n", trash); */

// if ((f_out_rec = fopen(out_rec, "w")) == NULL)
// { printf("output file \%s does\n", out_rec);
//   /*
//    * printf("not exist or is in wrong directory\n\n"); }
//   exit(); */

if ((f_out_non_rec = fopen(out_non_rec, "w")) == NULL)
{ printf("output file \%s does\n", out_non_rec);

  printf("not exist or is in wrong directory\n\n"); }
  exit(); */

if ((f_incident = fopen(incident, "r")) == NULL)
{ printf("incident history file \%s does\n", incident);

  printf("not exist or in wrong directory\n\n"); /* exit(); */
  fgets(trash, NONE, f_incident);
  printf("hey=\%s\n", trash);

  return;
}

void freew_fun(void)
{

  if (counter==0)
{
    if (((f_freeway = fopen(freeway_file, "r"))==NULL){
        printf("freeway file %s does\n", freeway_file);
        printf("not exist or is in wrong directory\n\n");
    }

    fgets(trash, NONE, f_freeway);

    //
    printf("%s", trash);
}

fscanf(f_freeway, "%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%]*%[^%}*
free_link_info[10] = freeway.link_time;
free_link_info[11] = (freeway.link_length*60)/freeway.free_speed;
/* printf( "%s\n%s\n%s\n%s\n%s\n%s\n%s\n%s\n%s\n", 
free_link_info[0],free_link_info[1],free_link_info[2], free_link_info[3],
free_link_info[4], free_link_info[5],free_link_info[6],free_link_info[7],
free_link_info[8],free_link_info[9],free_link_info[10]); */
}

// call route generator

else return;

}

void arterial_line_counter() //arterial counter

{
    //start of arterial counter

    if ((f_arterial = fopen(arterial_file, "r")) == NULL)
        {
            printf(" arterial file %s does\n", arterial_file);
            printf("not exist or is in wrong directory\n");
            /*
            exit();
            */
    }

    while((ch = getc(f_arterial)) != EOF) /*counting lines in farterial file*/
        {

            if (ch == 'n')
                arterial_no_of_lines++;

        }

    fclose(f_arterial);

} // end of arterial counter

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VITA

Chris Nutakor hailed from Ghana, a country in the region of West Africa. He graduated with a Bachelor of Science Degree in Civil Engineering from the University of Science and Technology, Kumasi, Ghana in 1989. After serving as a teaching assistant at the Department of Civil Engineering at the University of Science and Technology for one year, he entered the University of British Columbia in Vancouver, Canada in 1990. He earned a Master of Applied Science Degree in Civil Engineering with concentration in Transportation Engineering from the University of British Columbia in 1992. He taught as an Adjunct Professor at the Department of Civil Engineering in the University of British Columbia from the Fall of 1992 to Spring of 1993.

In the Fall of 1993, Chris Nutakor enrolled in the Ph.D. program at the Department of Civil Engineering with specialization in Transportation Engineering at Virginia Tech. Chris Nutakor also earned a Master of Arts Degree in Economics from Virginia Tech while studying for his Ph.D. Degree in Civil Engineering.

After completing his degree in 1996, Chris Nutakor hopes to pursue a career with the World Bank or the United Nations.

Christopher K. Nutakor