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Simulation Of IVHS On The Smart Corridor Using The Integration Model: Phase 1: Initial Investigations

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Simulation of IVHS on the Smart Corridor Using the INTEGRATION Model

Phase 1: Initial Investigations

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The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

EXECUTIVE SUMMARY

Background

A preliminary evaluation of potential benefits of ATIS on the Smart Corridor in Los Angeles was conducted by an Institute of Transportation Studies research team in 1988 and 1989 using the FREQ and TRANSYT traffic simulation models, Results of that study included recommendations for future research addressing requirements for more realistic simulation of the interactions between the freeway and parallel arterials of the corridor. A study was conducted in 1990 to review and assess existing traffic simulation models potentially suited to evaluate ATIS within a freeway/arterial corridor. Three models were recommended for further analysis and possible application: CONTRAM, SATURN, and INTEGRATION.

The 1991 research activity involved the application of the CONTRAM model to the Smart Corridor. Some difficulties were encountered in the modelling of the freeway portion of the corridor. It was decided in January 1992 to begin work with the INTEGRATION model.

Project Scope and Objectives

The general objective of the project is to evaluate the potential benefits of ATIS and ATMS on the Smart Corridor. The evaluation is directed to answer questions such as:

- What are the potential benefits of ATIS in terms of average travel time and travel time predictability?
- To what extend do non-equipped vehicles also benefit from the introduction of ATIS?
- Under what traffic conditions (demand levels and incidents) would the benefits of ATIS be greatest?
- What is the impact of ATIS market penetration?
- What are the potential benefits of ATMS strategies, primarily signal optimization on the arterials and ramp metering on the freeway?

Approach

In order to address these questions, a modelling approach was employed. Traffic simulation models are particularly valuable for identifying key operation and performance issues, and for evaluating ATIS concepts under a range of conditions. The INTEGRATION traffic simulation model was selected for this application, as this model appeared to exhibit many features directly related to simulation of ATIS and ATMS on a freeway/arterial environment.

Results

The present paper describes the initial investigations conducted at ITS with the INTEGRATION model. Before considering any ATIS or ATMS investigations on the entire Smart Corridor, it was found necessary to test the capabilities of the model on a series of hypothetical networks. Special attention was given to INTEGRATION's response to the need for realistic freeway simulation modelling and accurate representation of the differences between vehicles with and without ATIS.

INTEGRATION was first tested on a series of increasingly more complicated freeway networks. The model's output results were compared with analytical solutions and outputs from the FREQ freeway simulation model. INTEGRATION was found to be satisfactory in most cases, as bottlenecks were identified and located properly, and queue length patterns were similar to those estimated by the manual calculations or predicted by FREQ.

The model was then tested with regard to its ability to realistically simulate ATIS. A simplified "Diamond" network was designed for purposes of evaluating a number of model parameters and assessing system and user ATIS benefits on this simplified network. INTEGRATION proved to be a very useful tool for this type of application, because the model has the capability to represent different routing behaviors based on different access privileges to real-time information for each vehicle.

The capabilities of INTEGRATION to realistically simulate freeway network under recurrent and non-recurrent congestion conditions, in addition to provide a dynamic traffic assignment, make it a valuable and rather unique tool for networks analysis in the IVHS context. The study continued in the application of the INTEGRATION model to the Smart Corridor.

Only the first phase of the Smart Corridor investigations is described in this report, namely the generation of the reference base assignment. Before simulating the effects of ATIS and ATMS, it was necessary to develop a baseline (i.e., without incidents and without ATIS or ATMS) to compare with the performance of the system under various ATIS and ATMS control strategies. INTEGRATION was found to be a reliable model to represent as closely as possible the typical morning peak traffic conditions on the freeway and the signalized streets of the Smart Corridor.

Future Work

ATIS and ATMS investigations on the Smart Corridor will be conducted with the INTEGRATION model in order to address the questions raised in the project objectives. A comparison of the quantitative benefits of various ATIS and ATMS strategies will be carried out. A number of refinements will then be incorporated, including an expansion of the coded network to cover the entire Smart Corridor, and an extension of the simulation period to an entire day of operation.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Chapter 1: Introduction

1.1 BACKGROUND

The nation's network of highways, streets, and transit systems constitutes a transportation system that provides a basic source of mobility. However, congestion problems resulting from the growth of automobile ownership and use now threaten this mobility. In 1987, it was estimated [1] that congestion accounted for over 2 billion vehicle hours of delay on urban freeways and productivity losses from congestion only were estimated to cost the nation up to $100 billion.

Because of the magnitude of the problem, several approaches are being undertaken in an effort to reduce traffic congestion. In particular, increasing attention is being paid to the potential of advanced technologies to achieve improvements in the transportation system. The systems known as intelligent vehicle and highway systems (IVHS) represent a technology-based approach to improving the nature of transportation [2].

IVHS technologies involve a range of applications aiming at improving mobility, reducing congestion and improving safety: Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS) and Automatic Vehicle Control Systems (AVCS). ATMS includes urban traffic control systems, incident detection systems, highway and corridor control systems, High Occupancy Vehicles (HOV) priority treatment and ramp metering systems. ATIS technologies are designed to provide the traveler with navigational information and routing advice based on real-time traffic data using audio or visual media contained in the vehicle or on highway. AVCS technologies under development include variable speed control, radar braking, and automated headway and steering control.

Interest and support for IVHS has been increasing dramatically in the last few years in the United States as well as in Europe and Japan. However, there are a number of unanswered issues which still have to be addressed before any large scale deployment can take place. Specifically, the magnitude and consistency of the potential effects of these technologies on travelling conditions must be evaluated, either through operational field tests or research simulation studies. Operational field tests provide the opportunity to measure the benefits of IVHS in a real world highway environment and are clearly of vital importance for system design and evaluation. However, field tests of ATIS are limited in terms of the number of vehicles that can be simultaneously deployed and in terms of the range of conditions for which their performance can be examined.

Traffic simulation and assignment models are particularly valuable in this respect as a complementary aid to system design for identifying key operation and performance issues and for testing under a range of scenarios (system, network, traffic, etc.). There are a number of separate initiatives, currently carried out primarily in the United States, Canada and England to develop and use such models to assess ATIS and ATMS concepts. The particular study described in this report is an example of the use of a traffic model to evaluate the quantitative effects of route guidance systems on a specific network.

1.2 SCOPE AND OBJECTIVES

The general purpose of the research project is to assess the benefits of Advanced Traveler Information Systems (ATIS) on a real-life freeway corridor. The potential benefits of ATIS are assessed in terms of travel time savings, trip distances, travel time predictability and average speeds. The congestion effects of ATIS have to be analyzed both in terms of system effects and user effects. A sensitivity analysis of traffic conditions (recurring or incident-induced congestion) is also needed, and the impact of ATIS market penetration on the benefits is to be addressed. Through the use of a modelling approach, it is possible to evaluate many potential scenarios under many different circumstances, and many statistics on the behavior of the system can be obtained.

The INTEGRATION traffic simulation model has been selected to be applied on the Smart Corridor network in Los Angeles. Prior to investigations on the entire corridor, the INTEGRATION model was applied to a number of different traffic demand-supply networks in order to test the test the validity of the model and to evaluate various model features. The research study then continues in the initial application of the model to a portion of the Smart Corridor.

1.3 APPROACH

This project is a continuation of the original work by May et al.[3]. It was determined earlier that a dynamic model combining traffic simulation and traffic assignment in an integrated freeway/arterial environment was desirable for evaluating the potential benefits of ATIS on the Smart Corridor. Thus, a study was begun to investigate the candidate models potentially suited for the purposes of this project [4]. An initial application of the CONTRAM model was carried out and reported in 199 1 [5]. Problems with the CONTRAM program were significant, primarily with regard to modelling oversaturated conditions on the freeway.

The present report describes a new phase of the project that started in the Fall of 1991 and involves the use of the INTEGRATION traffic simulation model. INTEGRATION was developed specifically to deal with representation of networks combining freeways and arterials. Before simulating the Smart Corridor, it was felt necessary to determine the potential of the model through a series of tests.

1.4 ORGANIZATION OF THE REPORT

Chapter 2 of this report outlines the history and background of this study. Chapter 3 presents an overview of the INTEGRATION traffic simulation model. Chapters 4 and 5 describe initial applications of INTEGRATION that were performed for testing the model's capabilities with regard to freeway modelling (Chapter 4) and ATIS modelling (Chapter 5). Chapter 6 describes the design of the Smart Corridor application of INTEGRATION and how a reference base run assignment was derived. Finally, Chapter 7 provides an overall assessment of the study and discusses the potential for future research.

Chapter 2: Previous ATIS Evaluation Studies

A review of previous reported work on ATIS evaluation studies shows that evaluation through direct field observation is conspicuous by its absence in the literature, while the use of simulation models has become almost the standard way to address ATIS performance issues. This chapter presents an overview of the most important recently reported work on ATIS modelling, in Japan, Europe and North America.

2.1 IN JAPAN

Earliest reported route guidance related work was carried out by Kobayashi [6] who used a simulation model to assess benefits of the Japanese CACS route guidance system in Tokyo. It was estimated that the total network travel time could be reduced by 6% at a level of market penetration of 50 to 75%.

Tsuji et al. [7] applied a mathematical model in the context of the CACS project, and found that guided vehicles could save approximately 1 1%, which compared well with the observed reduction in the CACS system of some 12%.

2.2 IN EUROPE

Work at Southampton University by Breheret et al. [8] was carried out using the CONTRAM traffic assignment model. The unguided drivers were assigned based on an approximate stochastic user equilibrium whereas guided drivers followed optimum routes on the basis of current conditions. If multiple routes were used, guided drivers could obtain travel time benefits of up to 15% (under incident conditions). If, however, reassignment for guided drivers was based on a single shortest route, total network travel times increased which indicated possible problems with systems that advise single routes.

Smith and Russam [9] reported on a CONTRAM-based model study of the possible benefits of the AUTOGUIDE route guidance system in London. They found an estimated average trip time savings of 6 to 7% for guided vehicles. Non-guided vehicles also benefitted, resulting in overall network travel time savings of 2.5 to 6%.

Smith and Ghali reported an application of a modified version of CONTRAM carried out at the University of York [10]. They evaluated all eight combinations of four responsive traffic control policies and two route guidance strategies. They found that by combining local system optimal route guidance strategy with some of the familiar traffic control policies, a total network travel time reduction of at least 20% could be obtained.

Van Vuren et al. [11], from University of Leeds, used an adaptation of the SATURN traffic simulation model to develop a model of route guidance system in terms of a multiple user class equilibrium assignment, with vehicles divided into equipped and unequipped classes, the former being subdivided further depending on the routing criterion used and the quality of the information supplied.

2.3 IN NORTH AMERICA

May et al. [3] estimated the potential benefits of ATIS using the TRANSYT and FREQ simulation models on the Smart Corridor. It was assumed that the fraction of equipped vehicles is small enough so that link travel times are not affected by route changes of equipped vehicles. Travel time savings for guided traffic were found to be negligible under recurring congestion (less than 3 minutes per trip of 25 min length on average), while savings could be in the order of 10 minutes for a 40 minute trip under incident induced conditions.

Al-Deek [12] used a continuum approach in an idealized corridor to study the benefits of ATIS. The benefits were measured by comparing system optimal assignment, achieved by ATIS, with user equilibrium, which was assumed to occur in the absence of ATIS. The study demonstrated the potential benefits of ATIS under diverse environments of recurring congestion and identified some cases where ATIS is of marginal benefit and other cases where it is of little value.

Koutsopoulos et al. [13], from MIT, assumed that route guidance would reduce the perception errors in link travel times estimates, so that their model consists of a stochastic user equilibrium assignment of two user classes with different variances in the normal distribution of random perturbations in perceived link costs.

Mahmassani et al. [14], from University of Austin, built a model based on route-switching assumptions for drivers that receive dynamic network information supplied at the origin of the trip or along the way. A set of behavior rules governing path selection in the network was developed. Simulation experiments were performed to investigate the effects on overall network performance as well as the incidence of benefits across user information groups of four experimental factors: behavioral rules, sources of information, prevailing initial conditions, and market penetration.

Van Aerde et al. [15] used the INTEGRATION model to compare routes based on free-flow costs (for unguided drivers) and those based on minimum costs (for guided drivers). These assumptions are clearly not valid in congested situations, which probably accounts for the possible total network travel time savings they recorded of up to 21%. An interesting finding was, however, that a large proportion (85%) of total possible savings was achieved with the first 20% of equipped vehicles.

2.4 DISCUSSION

It is clear that the quantitative results of these studies are strongly influenced by the initial network-demand conditions, and the hypothesis about the route choice strategies and the interactions of guided and unguided drivers. Also, the models used in these studies are only valid under rather strong assumptions. However, this is not to belittle the importance of these simulation studies.

The interest for the use of traffic simulation models in IVHS applications was recently emphasized in the IVHS Dynamic Traffic Assignment and Simulation Workshop. This workshop was organized by the MITRE Corporation and was held in McLean, VA on March 19-20, 1992.

Participants including representatives from FHWA, the academic community, government laboratories, and MITRE, recognized the role of traffic simulation models as essential tools for traffic scientists and researchers in the IVHS context [16].

Chapter 3: Overview of the INTEGRATION Model

The INTEGRATION model was originally developed in response to a need for a traffic simulation model which could simultaneously represent signalized surface streets and freeways during congested traffic conditions. The model was created by Michel Van Aerde at University of Waterloo [17]. It has been under continued development at Queen's University in Kingston, Canada since 1985 by Van Aerde and his research team. During this time, capabilities to deal with in-vehicle route guidance systems, real-time traffic signal control, and their interactions, have been added. The model development has been sponsored, in part by the Ontario Ministry of Transportation, General Motors Research Labs, Queen's University and the Natural Sciences and Engineering Research Council of Canada.

The purpose of this chapter is to provide a general description of the INTEGRATION modelling approach, the model input data requirements, the model typical outputs, and an overview of the model's supporting modules. Chapters 4 and 5 will further discuss some of the model's features that are directly related to the Smart Corridor application.

3.1 GENERAL MODEL CHARACTERISTICS

The INTEGRATION modelling approach was originally proposed by Michel Van Aerde and a detailed description of the model components was provided in reference [17]. Even though the model has evolved substantially in the past several years, the base functionality of the model has remained largely unchanged. Several characteristics of INTEGRATION make it a powerful and rather unique tool for network analysis in the IVHS context. Some of the most important features of the model are highlighted in this section.

3.1.1 Individual Vehicles

The INTEGRATION model considers the behavior of traffic flow in terms of individual vehicles that have self-assignment capabilities. The model is not based on a time-slice approach; rather, it assigns individual vehicles sequentially to a network that is already loaded with any previous departures that have not reached their destination. At each node vehicles select which link to follow next to reach their desired destination based on the latest available minimum path tree.

The model's consideration of individual vehicles is primarily for purposes of improving the analysis resolution during the model's internal calculations. However, it does not necessarily require the user to collect or input data at the individual vehicle level. Instead, traffic flow characteristics and traffic demands can be specified by the user at an aggregate level, leaving it to the model routines to derive the more microscopic measures.

3.1.2 Modelling Freeways and Surface Streets

The model can represent combined freeway and arterial networks which experience time-varying congestion.

INTEGRATION models the behavior of freeways by treating each unique section of freeway as a pipe which has a certain maximum inflow rate, a maximum outflow rate, a maximum vehicle storage capacity, and travel time from entrance to exit which varies according to a user-specified travel time vs. link flow relationship. In addition, the model provides shock-wave queuing analysis and queue spill-back analysis. A more detailed discussion of INTEGRATION's capabilities with regard to freeway modelling is provided in Chapter 4 of this report.

The presence of traffic signals is represented by allowing the link to discharge traffic only during the effective green period. If the light is red, vehicles are not allowed to exit and must queue in a FIFO stack. During the effective green, the discharge pattern of one link automatically becomes the arrival pattern at the downstream end of the next link, subject to any time delays associated with travel along the link. This consideration for platooning allows the effect of coordination offsets to be modelled.

Ramp metering strategies are modelled as traffic signals with appropriate cycle times to produce the desired ramp metering rate.

Various types of fixed-time and real-time traffic control of signals or ramp meters can be represented, as the signal timings can be:

- held constant over time for either a common or different cycle lengths;

- made to vary over time based on a series of user specified time-of-day signal plans;

- optimized in real-time based on on-line traffic flow measurements subject to specified minimum/maximum cycle length for each signal (isolated intersection optimization);

- fully optimized in real-time considering SCOOT-like coordination.

Further information on modelling signal timing control within INTEGRATION is provided in paragraph 3.2.3.

3.1.3 Continuous Dynamic Queuing-Based Traffic Assignment

INTEGRATION reflects the most important attributes of congestion through its explicit account of queue growth/delay while maintaining a dynamic equilibrium traffic assignment. The explicit account of queue size and delay through the tracing of individual vehicles permits direct modelling of queue spill-back from upstream links, continuous modelling of traffic signal progression, and automatic delay of downstream link arrivals if they are held up at an upstream bottleneck. In addition, as the relative travel time between the shorter (but congested) route and a longer (but less congested) route changes, new arrivals will automatically redistribute themselves to avoid the congested link or area.

3.1.4 Different Driver/Vehicle Types

The INTEGRATION model allows the analyst to specify traffic flows in terms of any combination of five different driver/vehicle types. These different vehicle types are not intended to represent trucks, buses, or passenger cars. Instead, they refer to the capability to represent different routing behavior or different access privileges to travel time information for each vehicle. For instance, not all vehicles are allowed access to the continuously updated link travel time database. Some vehicles are provided routings based on minimum path trees which reflect the initial free-speed travel times through the network or the knowledge of some average historical traffic conditions, whereas other vehicles are routed based on minimum path trees which are supplied to the model from an external source.

A more detailed discussion of the routing capabilities of each of the five vehicle types is provided in Chapter 5 of this report.

3.1.5 Model Inputs/Outputs Structure

Figure 3.1 illustrates the general structure of the model inputs and outputs. Input data files (labelled 1 to 9) are briefly described in section 3.2, while the model outputs are presented in section 3.3.

3.2 INPUT DATA REQUIREMENTS

As illustrated in Figure 3.1 and Table 3.1, a typical INTEGRATION simulation run requires five mandatory types of input data, and four optional types of data. These data are separated into nine files which are briefly described in this section. Further details about the nature and structure of these inputs can be found in the Model User's Guide [18].

FILE NAME	STATUS	DESCRIPTION
Data File 1	Required	Node descriptor
Data File 2	Required	Link descriptor
Data File 3	Required	Signal timings
Data File 4	Required	O/D traffic demands
Data File 5	Required	Incident descriptor
Data File 6	Optional	Average link flows/travel times
Data File 7	Optional	Time-series of link flows/travel times
Data File 8	Optional	Routings for HOV vehicles
Data File 9	Optional	Time-series of multipath routings for veh. type 1

Table 3.1 : INTEGRATION Input Data Files

3.2.1 Data File 1: Node Coordinates for Graphics Purposes

This file lists primarily the X and Y coordinates of all zone centroids and nodes in the network. Node coordinate values are only utilized for displaying any real-time graphics on the screen (see

INTEGRATION Input/Output

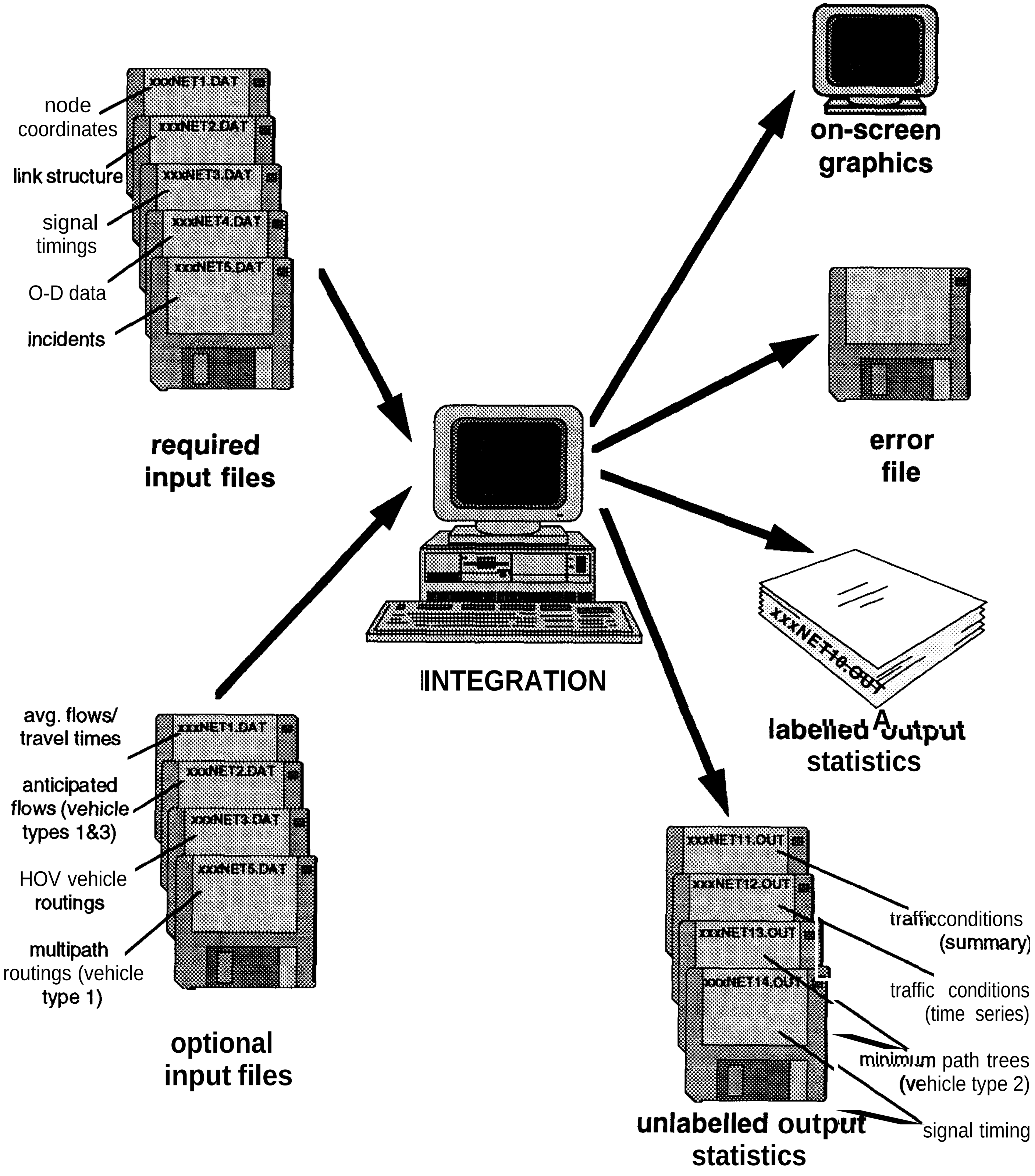


Figure 3.1

paragraph 3.3.1), or as part of the plots produced by INTMAP (see paragraph 3.4.7). A node designation is also provided for each node, indicating if the node is an origin or destination zone centroid, or only a intermediate point along vehicle trip paths.

3.2.2 Data File 2: Link Characteristics and Descriptor File

This file lists the start and end nodes of each link in the network. It also lists each link's length, free speed, platoon dispersion factor, as well as the non-queued travel-time relationship parameters, and the saturation flow rate per lane. These parameters control the traffic flow characteristics of a link. In addition, the number of lanes, any traffic signal controls, an HOV indicator, a surveillance level code and a qualitative descriptor or name of the link are also provided.

It should be noted that the link numbers need not be consecutive and that they need not be sorted for use within the model. However, such sorting may assist the user considerably in error-checking this data file and in interpreting the results of the simulation runs.

3.2.3 Data File 3: Signal Timing Plan Parameter Settings

The signal timings are specified in terms of the cycle length, offset of the start of first phase, the number of phases, and the durations of the green intervals for each phase. Lost times associated with each phase are also provided. The timings can be coordinated using a common cycle length, or can be run in isolation using different cycle lengths.

Simple fixed-time control can be modelled by providing the simulation model with only a single signal timing plan, which will remain active for the entire simulation period. Time-of-day fixed-time control can also be modelled by providing several different signal timing plans, each plan being in effect for the same user-specified duration.

When the automatic cycle and phase split optimization option is utilized, only the offsets and the lost times specified in the original signal timing plan are kept constant. The other parameters are optimized at the user specified time interval, based on the approach's volume/saturation flow ratios.

3.2.4 Data File 4: Origin-Destination Traffic Demand File

Traffic demands are specified to the model in terms of origin-destination traffic flow rates between specific origin-destination nodes. The time period for which these rates are assumed to prevail, and the distribution of the demand between different vehicle types in the network must also be specified.

The specified O/D hourly rates are translated internally within the model into corresponding individual vehicle departures. The individual vehicle departure headways can be completely uniform, completely exponential, or derived from a shifted-exponential distribution.

3.2.5 Data File 5: Incident or Lane Blockage Descriptor File

This file provides a description of the incidents to be modelled. The file indicates the incident number, the link impacted, the number of lanes affected, the start time, and the end time. Several incidents are allowed for consideration at the same time on different links, or at different times on the same link.

The incident is modelled as a capacity reduction at the link's downstream end. The reduction in capacity is calculated in view of the effective number of lanes of traffic that are expected to be eliminated. This number can be an integer value, to reflect a complete lane blockage, or a fraction, in order to indicate a partial lane blockage.

The type of diversion which occurs due to an incident is a function of the driver/vehicle types, travel times on the affected routes, and the level of access that drivers have to travel time information updates.

3.2.6 Data File 6 (optional): Average Travel Times During Entire Simulation Period

This file provides a listing of the average traffic conditions that are expected to prevail during the simulation run. This expectation is typically based on historical or forecasted data. The expected average link travel time database is utilized internally to assist in determining the routes that background (ie. unguided) traffic should take through the network.

This approach is used to represent routing decisions based on a driver's previous experience of network traffic conditions instead of current network travel times.

3.2.7 Data File 7 (optional): Time Series of Anticipated Link Flows/Travel Times

This file is very similar to Data file 6. The only difference is that file 6 only allows a single average travel time value to be specified for each link, while file 7 allows the modeller to inform some of the drivers of an entire time series of expected future travel times. The duration of the time periods may range from 1 to 60 minutes.

Such travel time data may represent additional knowledge of background traffic about typical variations in travel times during a peak period. In this case, these vehicles would route themselves based on different information, depending upon when they actually started their trip. This time variation is intended to represent the travel time experience they acquired on previous days during the same commute.

3.2.8 Data File 8 (optional): Static Path Tree for HOV Vehicles

This file is used to communicate a user specified path tree to the program for use by the HOV vehicle type 5. The use of this file, as a means of specifying the routes for HOV vehicles or buses, is preferred over the use of real-time route calculations, when the routing of HOV vehicles is known or constrained a priori. However, when the routing of HOV vehicles is to be a function of the relative attractiveness of HOV vs. non-HOV facilities, internal route calculations should be preferred, and tile 8 should not be used.

3.2.9 Data File 9 (optional): Time Series of Muitipath Background Traffic Routings

The purpose of file 9, with respect to vehicle type 1, is the same as the purpose of file 8 with respect to vehicle type 5. In other words, file 9 specifies at any node which link a vehicle should take next in order to reach the desired destination using a user-specified path. During each time period a series of equilibrium multipath routings for vehicle type 1 can be specified. By changing these routes and/or the weights on each route, from one time period to the next, these routes can also be made dynamic (time-varying).

3.3 MODEL TYPICAL OUTPUTS

As illustrated in Figure 3.1, the INTEGRATION model provides four types of simulation run outputs for interpretation by the model user, namely:

- On-screen graphics/text (displayed on video monitor);
- Error and diagnostic output file;
- Labelled output statistics;
- Unlabelled output statistics.

These outputs are briefly described in this section. Further information is provided in the Model User's Guide [18].

3.3.1 On-Screen Graphics/Text (Displayed on Video Monitor)

During the simulation run, the main graphics window at the center of the screen provides a graphical representation of the traffic network that is being modelled and the vehicles travelling through it. On-screen graphics display any free-flowing vehicles as green dots, while any queued vehicles are shown as red dots. Driver/vehicle types 4 and 5 are always shown in orange. Traffic signals are indicated as being either in an effective green or in an effective red mode state using a solid red/green box.

Time/departure statistics are provided in windows at the top of the screen. Specifically, the time that has elapsed during the simulation run, the number of vehicles that have started their trips, the number of vehicles that are en-route and the number that have arrived at their final destinations.

Any incidents are shown as solid yellow boxes, and the location and severity of the incident are noted in the traffic status report window at the center of the screen.

At user-specified time intervals, the graphics window can also display the minimum path trees that are in effect at that time.

During the course of the simulation, the zooming and panning features can be activated, allowing the user to confirm the correct network operation. For instance, one should watch for queued vehicles and ensure queues do not spill off of the network.

3.3.2 Error and Diagnostic Output File

This file serves two main functions. First, the file lists the network size constraints that have been built into the particular version of the model that has been run. The array dimensioning limits such values as the maximum node number, the maximum link number, etc.

Also, this file provides a listing of any errors that are detected by the model as having occurred during the course of initiating or running the model. These errors may either be detected during the course of the input data processing and/or during the actual execution of the simulation. Some of the errors are deemed fatal, which will cause the model logic to be terminated, while other errors are simply listed as warnings and allow the model to attempt to continue execution.

3.3.3 Labelled Output Statistics File (Output file 10)

This file contains six types of information:

a. Initial Data Input File Echo

This echo provides an analysis of each of the input data files, for purposes of input data verification and diagnostics;

b. Periodic O/D Travel Time Statistics

An O/D travel time matrix which contains the current travel times is generated, at a user-specified frequency;

c. System Oriented Link Statistics

This part provides sample statistics for each link in the network, namely the flows, total travel time, average travel time, volume/capacity ratio, number of stops and number of vehicles that are queued on each link;

d. Signal Timing Plan Summary

If any signal optimization was requested, the optimized signal timing settings for each signal in the network are indicated at the user-specified optimization interval;

e. Summary Statistics of Completed Trips

At the end of the simulation run, two further summary tables are generated. The first one summarizes the number of vehicles that completed their trip, the average trip time per arrival and the accumulation of the total trip times for all vehicles. A summary of the vehicle demand on the network, the number of vehicles that entered and left the network, and the number of vehicles left on the network after the simulation is completed is also provided. Such statistics are generated not only for all vehicle types combined, but also for each vehicle type by itself.

f. Incident Summary

A summary of any incidents that occurred in the network, listing the location, severity and duration of each incidents, is provided.

3.3.4 Unlabelled Output Statistics (Output files 11 to 14)

The final type of output statistics are in the form of unlabelled output files which are suitable as inputs into a spreadsheet, other programs, or even as one of the optional input data files for another INTEGRATION model run (Input Data Files 6 to 9).

Output file 11 produces a summary file of the traffic conditions that were experienced during the entire simulation run. Its format is identical to that of Input file 6. Output file 12 produces a time series of traffic conditions, similar to Input file 7. In addition, output files 11 and 12 produce more columns of data that are required for input as file 6 and 7, as the output files also provides link by link statistics of queue growth, volumes, speeds, number of stops and travel times.

Output file 13 produces a listing of minimum path trees in a format similar to Input files 8 and 9. Only one tree is produced per time period. Trees are output at intervals specified by the user, and are based on real-time travel information that exists at that point in time.

Output file 14 is in the same format as file 3 and contains a time series of signal timing plans, allowing the user to confirm fixed time plans or to check optimized plans.

3.4 INTEGRATION AND ITS SUPPORTING MODULES

The INTEGRATION model has been enhanced and applied at Queen’s University under sponsorship of General Motors Labs, as a tool to perform a dynamic traffic simulation study of the Travtek route guidance system in Orlando, Florida. As a part of this application, a series of coordinated supporting modules have been developed in order to generate the dynamic data inputs that are required by INTEGRATION [19].

The interrelationship between INTEGRATION and its supporting modules is illustrated in Figure 3.2. It is important to indicate that these programs use common data files. The development and combination of ASSIGN, QUEENSOD, MULTIPATH, Q-PROBE, ROUTCOMP, REAL-TRAN and INTMAP, in conjunction with the INTEGRATION model, represent a suite of programs for modelling a system such as Travtek.

3.4.1 ASSIGN

INTEGRATION has the ability to provide a dynamic traffic assignment for the non-guided traffic which will still be influenced by all other guided or non-guided vehicles. Such background traffic

INTEGRATION Supporting Modules

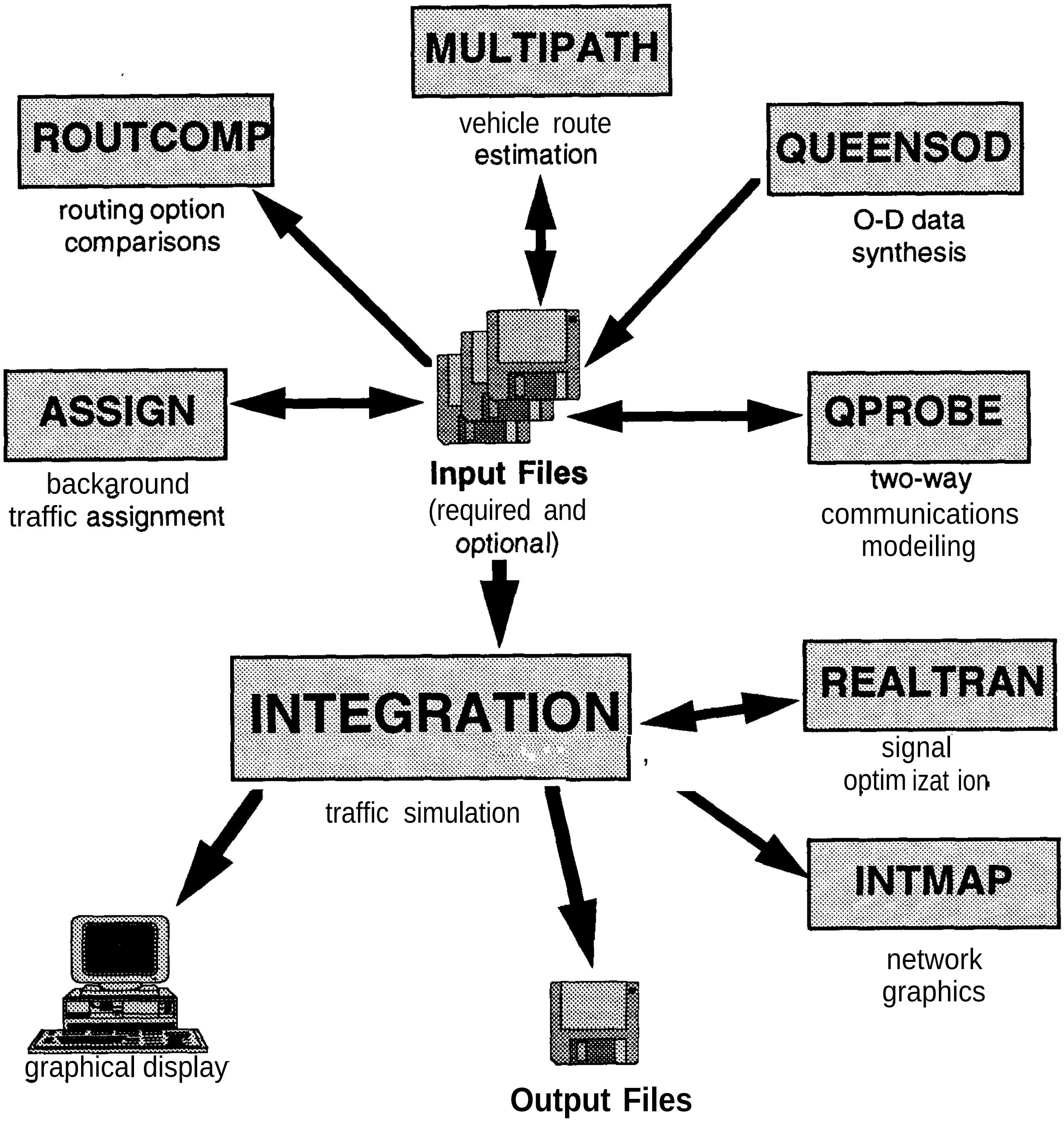


Figure 3.2

routings can be modelled by running the ASSIGN module [20] to compute estimated equilibrium routings for each of the time slices within the simulation period. ASSIGN is a general macroscopic traffic assignment model which computes a traditional multipath equilibrium and generates a set of minimum path trees for each destination and the appropriate fractions of drivers that should utilize each tree. The ASSIGN program is further described in Chapter 7 in view of its use within the Smart Corridor application.

3.4.2 QUEENSOD

As indicated in paragraph 3.2.4, one of the primary inputs for running INTEGRATION is a set of time-varying O/D demands. These data are often difficult and/or expensive to obtain. The QUEENSOD module [21] is a synthetic dynamic O/D demand estimator which can generate the O/D data from specified origin/destination locations, observed traffic flows, link travel times, and assumed driver's route choice. The program is also further described in Chapter 7 in view of its application within the Smart Corridor application.

3.4.3 MULTIPATH

In turn, QUEENSOD leads to a requirement to have a priori estimates of likely dynamic multipath routings through the network for each control period, before the actual O/D matrix is known. The MULTIPATH program have been developed to address this problem, and a detailed description of the mechanics and mathematics of the program can be found in reference [22].

3.4.4 Q-PROBE

QUEENSOD also requires an a priori knowledge of the travel times and traffic volumes on each link. The Q-PROBE module [23] can be used to generate a dynamic seed O/D matrix from traffic information that would be transmitted by RGS equipped vehicles. The Q-PROBE model processes dynamic traffic information transmitted by in-vehicle route guidance systems prototypes to a central traffic management center.

3.4.5 ROUTCOMP

The ROUTCOMP module [24] can be utilized with either the ASSIGN or the MULTIPATH program, to compare their respective routings against each other or against a simple All-or-Nothing Assignment. Specifically, the program considers the routes and the route weights for the two routing strategies, on an O-D pair basis, to determine simultaneously the overlap in the routes that were selected and the similarity in the weights that were assigned to each route.

3.4.6 REAL-TRAN

As mentioned earlier, INTEGRATION can generate real-time signal timing changes in response to the observed on-line link flow counts. A basic feature for performing on-line re-timing of the cycle length and phase splits of a series of isolated traffic signals is directly built-in into the model. In addition, the REAL-TRAN routine [25] has been added which permits a more comprehensive and complex optimization of a series of coordinated signals in a SCOOT-like fashion.

3.4.7 INTMAP

The INTMAP program is designed to produce plots of the networks used in INTEGRATION. There are two basic types of plots which can be produced: the first is a plot of an entire network, while the second consists of numerous plot-boxes each showing a specified region of a network.

Chapter 4: Freeway Modelling

4.1 INTRODUCTION

The purpose of this chapter is to describe the initial applications of the INTEGRATION model with particular emphasis on freeway performance modelling. The freeway performance modelling was found to be an area of most concern in the earlier simulation effort on the Smart Corridor. As mentioned in reference 5, some difficulties were encountered in the 1990/1991 phase of the project for representing oversaturated conditions on freeways with the CONTRAM model.

The most important requirements for freeway modelling are identified and briefly described in section 4.2, In section 4.3, the features of INTEGRATION that are directly related to freeway modelling are described. The model's capabilities were tested on three different freeway networks that were gradually more complex. These experiments are reported in sections 4.4, 4.5 and 4.6. Finally, general conclusions about the use of INTEGRATION for freeway modelling are given in section 4.7.

4.2 REQUIREMENTS FOR FREEWAY MODELLING

This section examines the most important features that a model should exhibit in order to properly simulate traffic flows on freeways under both free-flow and congested-flow conditions.

The simulation model must reflect the impact of traffic volume on link travel time under non-saturated conditions. In other words, the user must be allowed to specify the top part of the link speed/flow curve.

The modelling of queuing effects is the critical aspect in freeway simulation. Under saturated conditions, the link travel times must reflect the effects of queuing delays. The dynamics of queuing must be taken into account. The traffic situations can not be treated as isolated in time, but rather require to be considered in terms of previous flow conditions. Also, queue shock waves must be managed by the simulation.

The presence of hysteresis in the freeway typical speed/flow relationship makes the modelling more complicated. The speed of a given traffic flow can have two different values, depending upon whether this flow is congested or not.

The analysis must consider the impact of queued vehicles which spillback onto upstream links. Such a spillback may block the path of vehicles which do not necessarily intend to use the critical bottleneck.

The simulation model should be able to reflect the most important aspects of freeway weaving and merging areas. Special treatment is required for modelling ramp metering. Ideally the model should be able to handle different types of control (priority, normal, or mixed flow entry control).

The modelling of incidents is a very important feature. The model should reflect the characteristics of the incident and its effect on the traffic flows under both free-flow and congested flow conditions.

Interactions at the individual vehicle level (car-following, lane changing effects) may have to be considered, as these variables control the link's speed and capacity, but also the extent of any platooning and the risk of flow breakdown in response to incidents.

Some other features can be of interest, like the modelling of effects of introducing HOV lanes, or changeable message signs, or toll roads.

4.3 FREEWAY MODELLING WITH INTEGRATION

This section provides an overview of the most important characteristics of INTEGRATION which are directly related to freeway modelling.

4.3.1 Link Travel Times Under Uncongested Conditions

Link travel time represents the original free link travel time plus any increases that are strictly due to the increase in the magnitude of the traffic volume ("uniform delay").

The uniform delay effect is expressed as a function of the traffic volume. Specifically, all links are considered to follow a simplified version of the standard Bureau of Public Roads travel time function, which is shown in Eq.(l).

$$tt_i = tf_i\{1 + A(\frac{v_i}{c_i})^B\} \qquad \text{Eq. (1)}$$

where: tt_i = travel time on link i (sec)
tf_i = free flow travel time on link i (sec)
v_i = volume on link i (vph)
c_i = capacity of link i (vph)
A = increase in link travel time at capacity
B = change in rate of increase in link travel time

As an example, when A=1.0 and B=1.0 this general equation simplifies to a linear form.

In addition to the uniform delay, a "random delay" component is present in most traffic situations, which accounts for those delays that occur due to short-term stochastic variations in demand. As individual vehicle arrivals are tracked directly, most of the random variations in the arrival patterns of each link can be modelled explicitly.

4.3.2 Capacity

The queuing component of delay represents those delays that are incurred when demand exceeds capacity. While capacity is usually quoted as a flow per unit of time, at a fundamental level it is a more direct function of minimum headways between consecutive vehicle departures. Specifically, for each link a nominal minimum headway is specified that reflects the maximum rate at which vehicles can discharge from that link.

4.3.3 Oufflow Control, Inflow Control

When instantaneous demand exceeds capacity, the link will only serve vehicles at the minimum headway rate and a queue will result from any residual demand (outflow control). As the queue dissipates a shock wave may develop: the section of queued vehicles may move backward along the roadway. In addition, the rate of vehicle arrivals to a given link is limited by the saturation flow rate of this link (inflow control).

4.3.4 Link Travel Times Under Congested Conditions

Travel times under queuing conditions are estimated considering that all vehicles currently on the link will be discharged at the prevailing saturation flow headway, until the entire queue is served. Working backwards from the first vehicle in queue to the last, one can estimate when a new link arrival is likely to depart, if it were to join the queue at this instant in time. As this calculation is made frequently, the travel time estimate should be up-to-date and directly reflect any growth/decay in queue size or change in queue discharge rate.

4.3.5 Shock-Wave Analysis and Queue Spillback

Under oversaturated conditions, the model uses the parabolic speed-flow relationship proposed by Greenshield. The density is derived from the link speed by using the linear relationship shown in Eq.(2).

$$v = 2 v_c \{1 - (\frac{k}{k_j})\} \qquad \text{Eq. (2)}$$

where: v = speed
v_c = speed at capacity
k = density
k_j = jam density

The jam density and the capacity speed can both be derived from Eq.(l) once the A parameter is fixed.

An example of the speed-flow curve provided by this model is given in Figure 4.1. The shape of the top part of the curve is derived from A and B parameters (where A=0.7 and B=5.0) as shown in Eq.(l), while the bottom part of the curve is a parabola based on Eq.(2).

The on-line record of the number of vehicles on each link is used to automatically check if the maximum allowed number of vehicles is reached. If the current number of vehicles on the link exceeds the link's maximum density, spillback conditions exist and link entry privileges are limited. The procedure automatically constrains the upstream inflow capacity to the downstream discharge flow rate.

Speed-Flow Curve

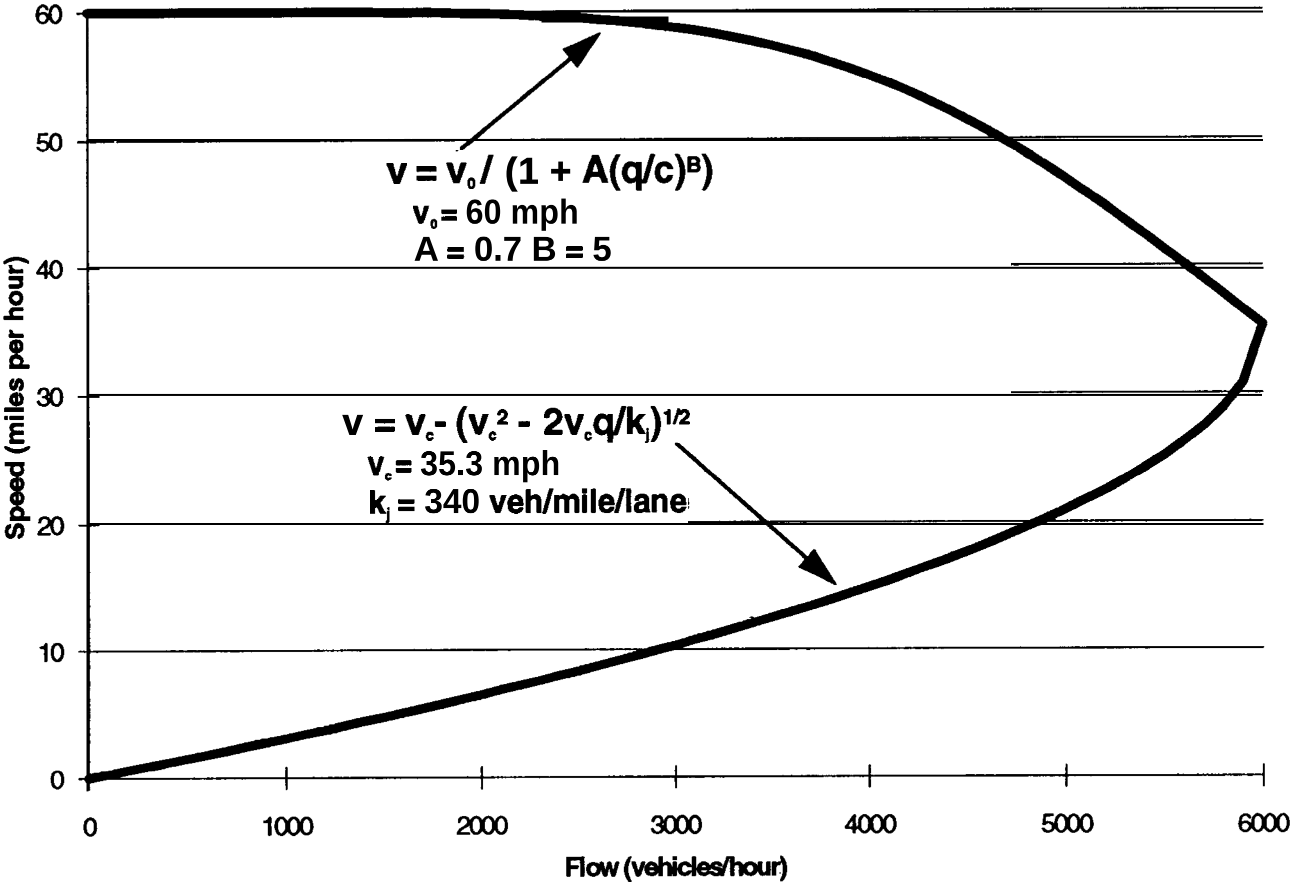


Figure 4.1

The maximum allowed density determined by INTEGRATION is a dynamic quantity, which changes continuously as the link outflow/speed change, as per the bottom half of the specified link speed/flow curve.

4.3.6 Platoon Dispersion

The model structure considers the formation and continuity of platoons on all link and facility types. While, there is less significance to platooning on freeways than there is on surface streets, it is possible to model the progression of platoons along a freeway or from a surface street onto a freeway. A shifted exponential distribution is used on signalized streets (as in TRANSYT); on freeways, one can utilize a normal or Gaussian distribution for travel times.

4.3.7 Ramp Metering

It is possible to model normal fixed-time ramp meters on a freeway on-ramp or on a freeway-to-freeway connector. Ramp meters are implemented within the modelling approach using a simple traffic signal, whose cycle length and green phase duration is selected to produce the average ramp metering rate.

The selection of an appropriate effective green time duration allows the operator to load on a certain number of vehicles per cycle, while the selection of a cycle length allows the user to model a desired hourly ramp metering rate. It can be seen that it is possible to both model the long-term limiting of excessive demand (5 to 30 minutes) and the more short-term balancing of fluctuations in arrival rates (5 to 120 seconds).

4.3.8 Incidents

It is possible for INTEGRATION to model incidents on both the freeway and the signalized arterial links. Such incidents are modelled as temporary blockages of the exit privileges (effectively increasing minimum headways) for a link and are specified in terms of incident start time, end time and effective number of lanes that are blocked.

The lack of an explicit time slice in the analysis allows the model to consider an incident which starts at any time and has any duration. The model allows any number of concurrent or overlapping incidents to be modelled. It is possible to model the various stages of an incident as a series of consecutive incidents, with progressively less severity as the vehicle is removed from the freeway onto the shoulder and eventually off the freeway.

There is no explicit linkage between the occurrence of an incident and the re-routing of traffic. Instead, only an indirect linkage exists when the queues that are associated with an incident increase the travel time on that link, and therefore may result in a re-routing of traffic. The amount of re-routing associated with an incident will therefore depend upon the severity of the incident, the amount of remaining spare capacity, the current level of traffic demand on this link, and the travel time and congestion status of the other alternative routes.

4.4 FREEWAY STRAIGHT-PIPE BOTTLENECK

4.4.1 Network and Demand Data

A linear test freeway bottleneck segment is to be analyzed to predict its performance for a specified demand-supply situation. The following paragraphs first describe the demand and supply elements. Then, the theoretical results are predicted with an analytical solution based on shock-wave theory. Finally, the FREQ and INTEGRATION simulation runs are presented and compared.

The supply side of the network is depicted in Figure 4.2. The directional freeway segment is divided into five subsections. The first subsection through the fourth is composed of three lanes. The fifth subsection is two lanes. All subsections are 2000 feet long. Capacity values of 2000 vehicles per hour per lane are assumed for the freeway. The free flow speed is set to 60 miles per hour, the A parameter is set to 0.7 and the B parameter is equal to 5.0. The demand pattern is given in Table 4.1. There is one origin and one destination. The traffic hourly rates are chosen so that congestion conditions occur. When demand exceeds capacity, the flow in the fifth subsection is no longer equal to demand but is limited by capacity. Excess demand at the bottleneck is stored in upstream subsections, and the traffic performances of these upstream subsections are affected.

The results of simulation runs using INTEGRATION are compared with the results from two different methods: an analytical solution using shock-wave theory, and simulation runs from FREQ. The results of these different approaches are presented and interpreted in the following paragraphs.

4.4.2 Comparison of INTEGRATION to Analytical Results

An analytical shock-wave approach of the problem is performed first. It is necessary to derive the volume-density curves for both the three-lane section and the two-lane section of the network.

Since the intent of the analysis is to compare the results of the shock-wave approach and the results of the INTEGRATION simulation run, the volume-density curves to be used in the analytical shock-wave approach must be the same as the ones used by INTEGRATION. The INTEGRATION speed-flow model was described in paragraph 4.3.1 for the top part of the curve and in paragraph 4.3.5 for the bottom part of the curve. An example of an INTEGRATION typical link speed-flow curve was shown on Figure 4.1.

The volume-density curves to be used in the shock-wave analysis must be also be derived in two parts: using the Bureau of Public Roads travel time function (given in Eq.1) for the left side of the curves, and using a parabolic function for the right side. The resulting curves are shown graphically in Figure 4.3.

Figure 4.3 also provides the shock-wave diagram analysis. Information about queue lengths and queue starting and ending times can be directly determined from the triangle labelled F. Specifically, the queue from the three-lane to the two-lane section should begin forming at about

Freeway Straight-Pipe Bottleneck
Test Network

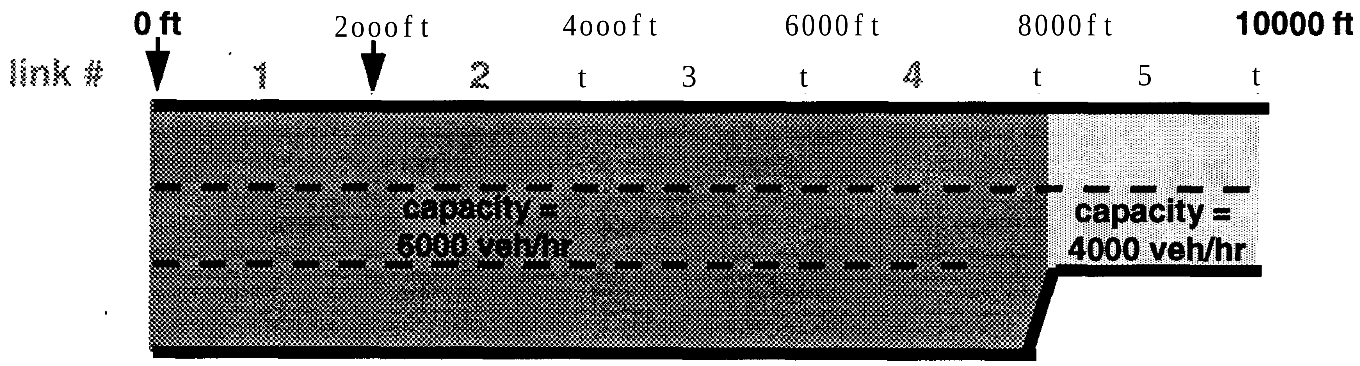


Figure 4.2

Freeway Straight-Pipe Bottleneck
Demand Pattern

Time Slice	Time Period	Input Origin
1	8:00 - 8:10	3000
2	8:10 - 8:20	4000
3	8:20 - 8:30	5000
4	8:30 - 8:40	3000
5	8:40 - 8:50	3000

Table 4.1

Freeway Straight-Pipe Bottleneck

Flow/Density and Shock-Wave Diagrams

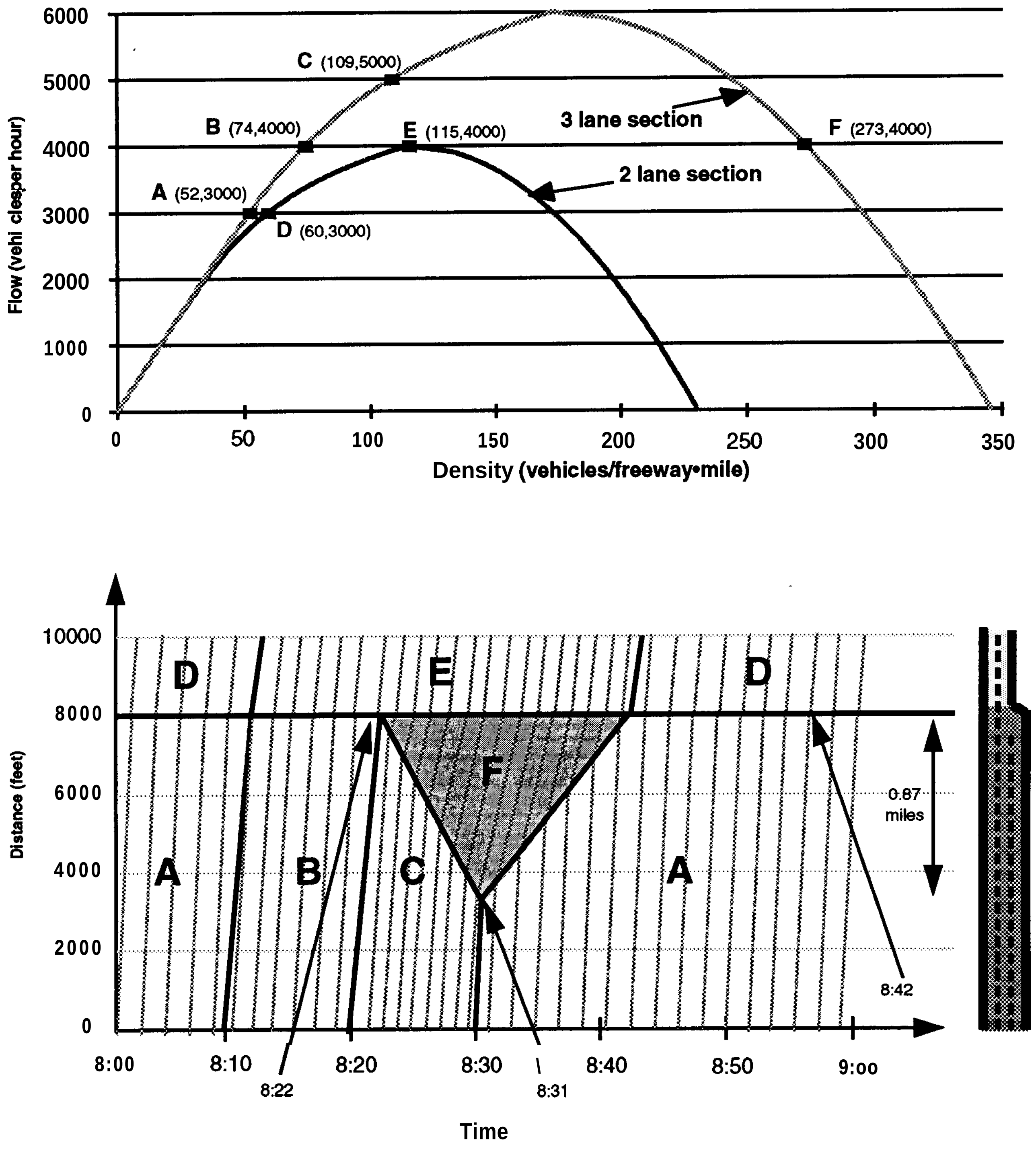


Figure 4.3

8:22, reach its maximum at about 8:31, and dissipate at about 8:42. The length of the queue at its maximum point is 0.87 miles.

The INTEGRATION simulation run results (from the same network and supply data sets) are close to the theoretical values. Using the graphical display from INTEGRATION (as described in 3.3.1), it appears that the queue in subsection 4 begins approximately 22 minutes into the simulation (8:22), reaches its maximum point 10 minutes later (8:32), and is completely dissipated in 12 more minutes (8:44). The maximum queue predicted by INTEGRATION is about 0.9 miles.

4.4.3 Comparison of INTEGRATION to FREQ Results

A demand-supply analysis of the problem is also performed using the FREQ simulation model. The FREQ family of freeway simulation models has been in existence since the 1960's [26]. FREQ is a macroscopic deterministic simulation model in which time is broken into equal discrete time-slices and the directional freeway segment is divided into homogeneous subsections with demands and capacities remaining constant during each time slice. At the end of each time slice, a queue grows or decays according to the difference between demand rates and capacities. FREQ provides, among other things, contour maps of link flows, speeds, and densities.

Table 4.2 shows tables of travel times, volume-capacity ratios and densities produced by FREQ and by INTEGRATION. The link flow parameters used in the INTEGRATION link data file were selected so that the speed-flow relationships used by the two models were compatible. Specifically, the INTEGRATION A parameter (see paragraph 4.3.1) is 0.7, since FREQ uses a capacity speed of 35 mph for a free flow speed of 60 mph. This is derived from Eq.(l); with v/c=1, the A parameter is:

$$A = \frac{v_o}{v_c} - 1 \cong 0.7 \qquad \text{Eq. (3)}$$

The B parameter determines the shape of the speed-flow curve. It is set at 5 to approximate the shape of the FREQ speed-flow curve.

It can be seen in Table 4.2 that the link by link traffic performances predicted by FREQ and INTEGRATION for this particular problem are reasonably close. Both models predict that subsection 5 is the cause of the congestion and that the effect of the congestion is displayed upstream of the bottleneck. The travel time and density patterns within the bottleneck subsection are very similar. The upstream effects also follow the same patterns in terms of the number of subsections affected and the resulting link travel times and densities. Some minor differences appear when INTEGRATION predicts slightly more severe reduction in travel time under congestion conditions (subsections 2 and 3 in time slice 3), but effects last longer with FREQ (subsection 3 in time slice 4).

The traffic performances predicted by FREQ and INTEGRATION for this problem are similar. However, some discrepancies were shown. A possible explanation for these discrepancies is the fact that FREQ uses a time slice approach in which freeway congestion can only begin and end

Freeway Straight-Pipe Bottleneck

Comparison of Performance Tables

INTEGRATION **FREQ**

Travel Time Summary Tables (seconds)

INTEGRATION

Time Slice	1	2	3	4	5
1	23	23	23	23	26
2	24	24	24	24	37
3	28	34	72	85	39
4	23	23	23	62	39
5	23	23	23	23	26

Link Number

FREQ

Time Slice	1	2	3	4	5
1	23	23	23	23	24
2	24	24	24	24	39
3	24	25	45	76	39
4	23	25	59	91	39
5	23	23	23	47	24

Link Number

Volume/Capacity Summary Tables

INTEGRATION

Time Slice	1	2	3	4	5
1	0.48	0.46	0.44	0.42	0.60
2	0.66	0.65	0.64	0.64	0.93
3	0.82	0.80	0.73	0.67	1.00
4	0.52	0.55	0.62	0.67	1.00
5	0.50	0.50	0.50	0.53	0.83

Link Number

FREQ

Time Slice	1	2	3	4	5
1	0.50	0.50	0.50	0.50	0.75
2	0.67	0.67	0.67	0.67	1.00
3	0.83	0.67	0.67	0.67	1.00
4	0.50	0.50	0.50	0.67	1.00
5	0.50	0.50	0.50	0.54	0.81

Link Number

Density Summary Tables (veh/mile/link)

INTEGRATION

Time Slice	1	2	3	4	5
1	16	18	17	17	28
2	24	24	22	24	56
3	34	43	80	83	56
4	16	18	17	43	56
5	24	26	25	25	33

Link Number

FREQ

Time Slice	1	2	3	4	5
1	17	17	17	17	26
2	23	23	23	23	57
3	30	25	44	74	57
4	17	19	43	89	57
5	17	17	17	37	29

Link Number

Table 4.2

at boundaries between time slices, whereas INTEGRATION uses a continuously updated simulation approach. Table 4.3 summarizes the results from the three modelling approaches: INTEGRATION, FREQ, and the shock-wave (analytic) solution:

Model	Queue Start Time	Maximum Queue Time	Maximum Queue Length	Queue End Time
Shock-Wave	8:22	8:31	0.87 miles	8:42
INTEGRATION	8:22	8:32	0.9 miles	8:44
FREQ	8:20	8:30	1.1 miles	8:44

Table 4.3: Freeway Straight-Pipe Bottleneck - Summary of Modelling Results

4.5 FREEWAY ON-RAMP BOTTLENECK

4.51 Network and Demand Data

A directional freeway segment with two on-ramps is to be analyzed. This problem is similar to the example problem used in the textbook ***Traffic Flow Fundamentals*** [27]. The supply pattern is depicted in Figure 4.4. The directional freeway segment is divided into three subsections. The first subsection is three lanes wide extending two and a half miles from the upstream end of the freeway segment to the first on-ramp. The second subsection is also three lanes wide and extends one mile from the first on-ramp to the second on-ramp. The third and last subsection, which extends from the second on-ramp to the downstream end of the freeway segment, is 1 mile long and four lanes wide. Capacity values of 1800 vehicles per hour per lane are assumed for the freeway. There is no control at the ramps. Since the ramp demands are relatively low in comparison with the ramp capacities and freeway shoulder lane demand, any congestion will effect freeway vehicles only.

The demand pattern is shown in Table 4.4. There are three origins along the directional freeway: the freeway mainline origin 0,, the first on-ramp 0, and the second on-ramp O_3. All the traffic is destined to the downstream end of the freeway segment. During the afternoon peak period, the traffic demand hourly rates are given for each origin in each 15-minute period.

Again, output from the INTEGRATION model is compared with theoretical values and the results from the FREQ model. Discussion of these comparisons is in the next two paragraphs.

4.5.2 Comparison of INTEGRATION to Analytical Results

The shock-wave analysis performed for the freeway on-ramp bottleneck is shown is Figure 4.5. The q-k curve shown at the top of the figure is the same as is used in the INTEGRATION runs. The parameter values for the curve are: v_o = 62 mph, A=0.78, and B=10. The curve was derived using the techniques described in paragraph 4.3.5.

Freeway On-Ramp Bottleneck

Test Network

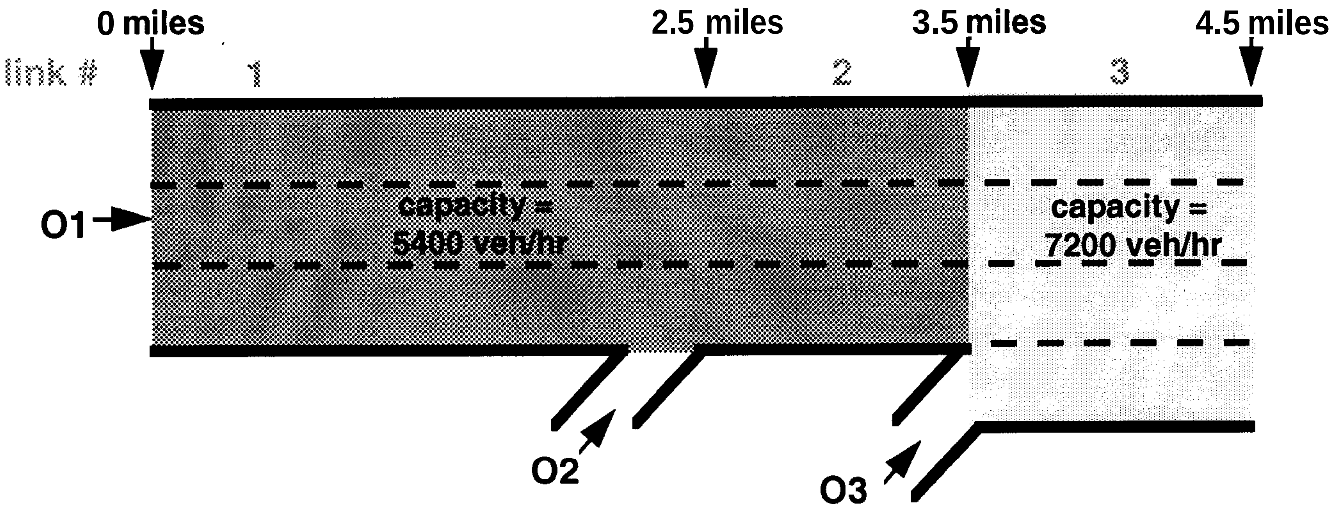


Figure 4.4

Freeway On-Ramp Bottleneck

Demand Pattern

Time Slice	Time Period	Input Origin		
		01	02	03
1	4:45 - 5:00	4800	400	800
2	5:00 -5:15	5000	800	800
3	5:15 - 5:30	5000	800	800
4	5:30 - 5:45	3800	800	800
5	5:45 - 6:00	3200	200	600

Table 4.4

The shock-wave diagram shown at the bottom of Figure 4.5 is for the section of the freeway where queuing occurs. From the network and demand data, it can be shown that the only bottleneck in the system occurs when the demand of the freeway and ramp traffic (at O_2) exceeds 5400 vehicles/hour between 5:00 and 5:30. This time period and freeway section are shown on the shock-wave diagram.

The theoretical model predicts the queue begins forming at 5:03, reaches its maximum length at approximately 5:31 (when it reaches a length of 1.75 miles) and dissipates around 5:51 P.M. The INTEGRATION simulation run results (from the same network and supply data sets) are close to the theoretical values. The graphical display from INTEGRATION shows that the queue in begins at approximately 5:05, reaches its maximum point 27 minutes later (5:32), and is completely dissipated in 16 more minutes (5:48). The maximum queue predicted by INTEGRATION is about 1.75 miles (using the graphical display).

4.5.3 Comparison of INTEGRATION to FREQ Results

Table 4.5 presents the travel time, volume-capacity ratio and density tables predicted by FREQ and INTEGRATION. Special attention is given to bottleneck identification and queue length in analyzing the model outputs. Both models identify subsection 2 as the bottleneck, and show that the effects of the bottleneck are displayed in subsection 1. FREQ and INTEGRATION predict that congestion conditions are encountered at the same location and within the same time period. It is interesting to note that even though demand exceeds capacity in subsection 2 during only two time slices (time slices 2 and 3), congestion effects last during three time slices.

Travel times within the bottleneck and within the queues are very comparable. The density patterns, and therefore the queue patterns are also very close with the two models. The largest discrepancies are the volume/capacity ratios for the first time slice. The reason for this is that INTEGRATION travel times and densities are measured at the end of the time period, while the volumes are a measurement taken over the entire time slice. Consequently, when a network is first started, the volumes include a warm-up period of light traffic, while the travel time and density data come from a stable network.

Again, Table 4.6 is a summary of the results from the three modelling approaches: INTEGRATION, FREQ, and the shock-wave (analytic) solution:

Model	Queue Start Time	Maximum Queue Time	Maximum Queue Length	Queue End Time
Shock-Wave	5:03	5:31	1.75 miles	5:51
INTEGRATION	5:05	5:32	1.75 miles	5:48
FREQ	5:oo	5:30	1.7 miles	5:45

Table 4.6: Freeway On-Ramp Bottleneck - Summary of Modelling Results

Freeway On-Ramp Bottleneck

Flow/Density and Shock-Wave Diagrams

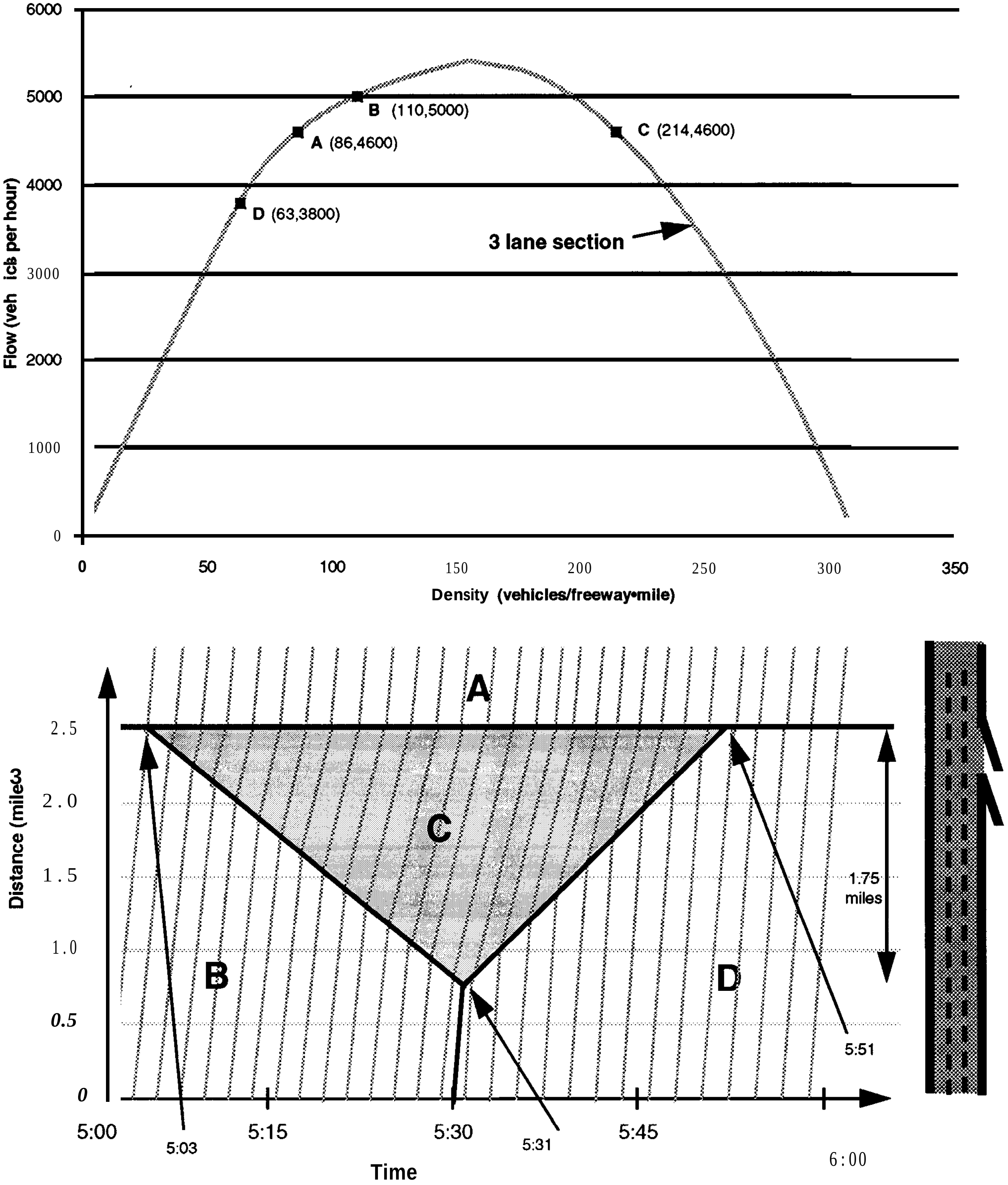


Figure 4.5

Freeway On-Ramp Bottleneck
Comparison of Performance Tables

Travel Time Summary Tables (seconds)

INTEGRATION

Time Slice	Link Number		
	1	2	3
1	173	79	63
2	225	97	67
3	290	103	68
4	188	100	67
5	145	58	57

FREQ

Time Slice	Link Number		
	1	2	3
1	161	67	64
2	200	103	64
3	281	103	64
4	273	103	64
5	191	63	62

Volume/Capacity Summary Tables

INTEGRATION

Time Slice	Link Number		
	1	2	3
1	0.72	0.70	0.58
2	0.86	0.97	0.83
3	0.86	1.00	0.86
4	0.86	1.00	0.86
5	0.64	0.79	0.70

FREQ

Time Slice	Link Number		
	1	2	3
1	0.89	0.96	0.83
2	0.85	1.00	0.86
3	0.85	1.00	0.86
4	0.85	1.00	0.86
5	0.62	0.66	0.58

Density Summary Tables (veh/mile/link)

INTEGRATION

Time Slice	Link Number		
	1	2	3
1	31	38	25
2	42	49	28
3	53	51	28
4	26	50	28
5	17	18	15

FREQ

Time Slice	Link Number		
	1	2	3
1	29	32	27
2	34	51	28
3	48	51	28
4	46	51	28
5	24	21	18

Table 4.5

4.6 SANTA MONICA FREEWAY

4.6.1 Network and Demand Data

The eastbound section of the twelve-mile Santa Monica freeway is the next segment used in the freeway modelling process. Again, results from the INTEGRATION model are compared with those from FREQ. Due to complexity of the network and time constraints, an analytical solution (or real data from the freeway) is not provided for this example.

The network consists of 32 subsections with 16 on-ramps and 15 off-ramps (note that some off-ramps are not used). The network design is illustrated in Figure 4.6 (note that both the on-ramps and off-ramps are actually both on the right side of the freeway; the figure shows them on the opposite side for clarity). Table 4.7 describes the demand data for the network, consisting of 17 origins and 16 destinations over eight 30-minute time slices. It also lists the total O-D data (58,817 vehicles) for the entire period; eight separate tables (one for each 30 minute period) were actually used as input to the simulation model. A synthetic O-D run from FREQ was originally used to generate the O-D table. Note that there are significant differences in the demand quantities for different origins and destinations. Most traffic originates from node 1 and most traffic has a destination of node 16. Table 4.8 provides link by link characteristics used to code the network with the two models.

4.6.2 Comparison of INTEGRATION to FREQ Results

The elements that are given special consideration in the validation process were bottleneck location, queue length, and link by link travel times.

Table 4.9 highlights the main freeway congestion patterns as predicted by the two simulation models. The table suggests that the queue patterns predicted by both models are reasonably close. In particular subsections 29 and 13 are clearly identified as major bottlenecks. The queue starting and ending times are also similar, even though INTEGRATION tend to show congestion conditions (queues) that are somewhat longer than FREQ.

The observed speeds and travel times can be used as another type of comparison between the outputs of the two models. The average speeds listed in Table 4.10 show that the areas of congestion are comparable between the two models. Table 4.11 lists the link by link travel times (in seconds) predicted by FREQ and INTEGRATION; these data are summarized in Figure 4.7. The results appear to be very similar. It is interesting to note that the fit is relatively good under both congested and uncongested traffic conditions.

The main difference that is observable between the two models is that INTEGRATION results indicate slower speeds within congestion regions. Table 4.12 shows that INTEGRATION travel times are generally higher in the middle of the simulation (i.e., time slices 4-6 and links 7-29). It is not entirely clear why this is the case. One explanation is that the two simulations have different methods for dealing with dissipating queues. In FREQ, as a queue is decreasing, the cars in the link at the back of the queue are instantaneously transferred to the next link in the queue, and traffic in the first link is immediately restored to a lower density. In contrast, the microscopic nature of INTEGRATION has cars in the section of the queue that is dissipating gradually move into the next (congested) section. Thus, it takes longer for the congestion in the first link to dissipate, and travel times are somewhat higher for cars in that link. This hypothesis is as yet untested, and should be the subject for further research.

4.7 CONCLUSIONS

Special attention was given to freeway modelling in this application. It was felt critical that the simulation model be able to accurately represent oversaturated conditions on freeways. Before INTEGRATION was applied to the Smart Corridor network for IVHS investigations, the model was tested on a series of freeway networks that are increasingly complicated. INTEGRATION output results were compared with analytical solutions and outputs from the FREQ freeway traffic simulation model. The FREQ model had been previously validated and extensively applied in similar studies. INTEGRATION was found to be satisfactory in most cases, as bottlenecks were identified and located properly, and queue length patterns were similar to those estimated by the manual calculations or predicted by FREQ.

Santa Monica Freeway

Test Network

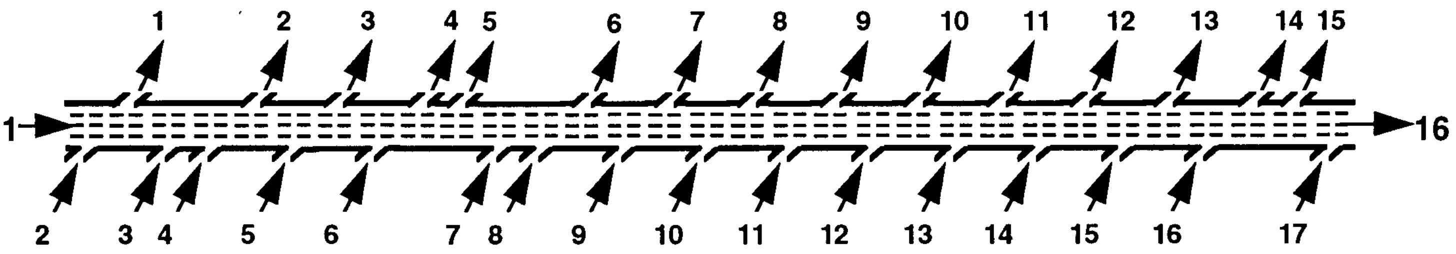


Figure 4.6

Demand Data (aggregate 6-10 A.M.)

		destination																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**Total**
origin	1	1778	1447	0	634	448	0	346	293	218	0	268	462	492	978	2302	4341	**14006**
	2	1517	1232	0	528	384	0	301	252	178	0	223	389	421	874	2038	3772	**12108**
	3	0	393	0	168	121	0	94	79	58	0	72	125	134	278	647	1214	**3385**
	4	0	164	0	71	51	0	39	34	24	0	29	52	57	114	268	499	**1402**
	5	0	0	0	81	59	0	47	39	26	0	33	59	64	134	311	572	**1425**
	6	0	0	0	91	62	0	49	40	30	0	37	64	67	127	303	571	**1441**
	7	0	0	0	0	0	0	64	54	39	0	51	84	92	190	438	829	**1842**
	8	0	0	0	0	0	0	119	101	70	0	89	155	168	347	811	1501	**3360**
	9	0	0	0	0	0	0	59	48	33	0	42	74	82	171	396	723	**1628**
	10	0	0	0	0	0	0	0	89	62	0	77	137	149	319	732	1345	**2909**
	11	0	0	0	0	0	0	0	0	82	0	102	177	192	403	927	1728	**3611**
	12	0	0	0	0	0	0	0	0	0	0	83	143	156	331	756	1423	**2893**
	13	0	0	0	0	0	0	0	0	0	0	64	111	121	252	583	1088	**2218**
	14	0	0	0	0	0	0	0	0	0	0	0	70	76	164	377	699	**1386**
	15	0	0	0	0	0	0	0	0	0	0	0	0	78	165	381	710	**1334**
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	173	394	734	**1301**
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2569	**2569**
	Total	**3296**	**3236**	**0**	**1572**	**1124**	**0**	**1117**	**1029**	**821**	**0**	**1169**	**2103**	**2349**	**5021**	**11664**	**24317**	**58817**

Table 4.7

Santa Monica Freeway

Network Data

Subsection Number	Length (miles)	Capacity (veh/hr)	#Lanes	Subsection Number	Length (miles)	Capacity (veh/hr)	#Lanes
1	0.61	6000	3	17	0.42	9500	5
2	0.49	8850	5	18	0.44	9470	5
3	0.30	7200	4	19	0.55	10902	6
4	0.70	9400	5	20	[illegible]	9500	5
5	0.38	9350	5	21	0.20	10098	6
6	0.42	9000	5	22	0.41	12103	7
7	0.53	9000	5	23	0.21	12103	7
8	0.21	8700	5	24	0.29	10302	6
9	0.07	9198	6	25	0.19	11900	7
10	0.09	8600	5	26	0.36	12502	7
11	0.29	9000	5	27	0.13	11347	7
12	0.32	9300	5	28	0.29	10152	6
13	0.75	8000	5	29	0.13	9852	6
14	0.11	8100	5	30	0.18	9000	6
15	0.07	9000	6	31	0.17	7500	5
16	0.27	8500	5	32	0.13	9300	6

Table 4.8

Santa Monica Freeway

Comparison of Main Freeway Congestion (Eastbound Direction)

FREQ

Time	Bottleneck Location	Queue Length (miles)
7:00	Subsection 29	1.93
7:30	Subsection 29 Subsection 13	3.73 1.43
8:00	Subsection 29	8.02
8:30	Subsection 29 Subsection 14	3.60 2.18
9:00	Subsection 29 Subsection 21 Subsection 14	1.68 0.81 1.99
9:30	Subsection 14	0.31

INTEGRATION

Time	Bottleneck Location	Queue Length (miles)
7:00	Subsection 29	1.74
7:30	Subsection 29 Subsection 13	2.86 0.44
8:00	Subsection 29	6.84
8:30	Subsection 29	7.21
9:00	Subsection 29 Subsection 13	3.98 1.93
9:30	Subsection 29 Subsection 24 Subsection 13	0.75 0.37 0.75

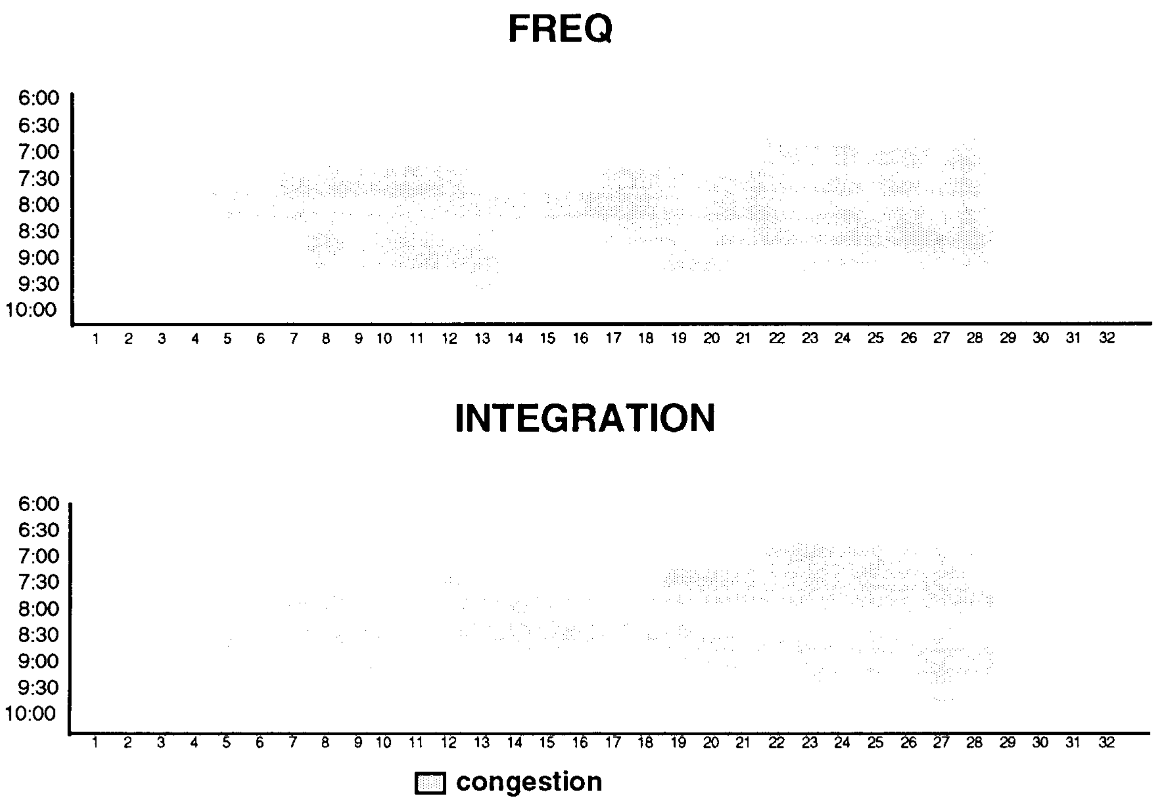


Table 4.9

Santa Monica Freeway
Comparison of Link Speeds

Average Speeds (mph) for INTEGRATION

Time Slice	1	2	3	4	5	6	7	6	9	10	11	12	13	14	15	16	17	16	19	20	21	22	23	24	25	26	27	26	29	30	31	32
1	61	59	61	60	59	60	59	63	67	67	61	61	60	67	67	62	60	60	60	64	60	62	63	61	63	59	59	58	59	43	60	59
2	56	57	58	59	59	60	56	45	67	42	61	58	43	40	38	35	39	46	43	36	42	38	45	43	58	29	20	23	31	36	60	59
3	59	35	37	57	43	54	34	51	67	42	24	16	40	37	38	39	41	22	16	23	23	15	19	25	20	16	20	23	34	36	60	59
4	58	40	35	57	35	14	12	11	11	12	10	12	19	19	18	17	15	15	15	20	22	15	17	23	22	17	21	23	34	36	60	59
5	31	35	48	54	18	14	15	15	17	16	15	16	26	22	24	19	19	19	18	22	25	17	20	26	22	17	20	23	34	36	40	59
6	34	37	50	42	31	15	16	15	19	20	15	16	31	37	30	24	22	21	20	27	26	18	20	29	21	17	22	24	34	36	43	52
7	47	37	38	59	52	60	59	35	19	21	16	16	31	37	38	43	41	45	45	32	33	20	21	32	32	18	22	24	31	36	60	59
6	61	59	61	60	59	60	59	63	67	67	61	61	60	67	67	62	60	60	60	64	60	62	63	61	63	62	59	62	59	47	60	59

Link Number

Average Speeds (mph) for FREQ

Time Slice	1	2	3	4	5	6	7	6	9	10	11	12	13	14	15	16	17	16	19	20	21	22	23	24	25	26	27	26	**29**	30	31	32
1	61	59	59	60	59	60	59	59	59	59	60	59	58	58	58	58	58	58	58	57	57	58	58	57	57	58	57	57	56	41	58	59
2	59	57	57	57	57	57	57	57	57	57	57	57	54	55	55	55	55	55	54	36	34	38	32	30	31	23	24	25	35	40	57	58
3	58	56	56	57	56	56	47	37	34	33	28	25	32	34	36	34	31	25	20	23	25	18	20	25	21	18	23	25	35	40	57	57
4	58	56	56	34	23	15	14	14	15	15	13	14	23	22	20	21	20	19	19	23	25	19	21	26	22	18	23	25	35	40	56	57
5	57	56	56	22	20	17	19	20	20	20	17	18	28	27	24	25	24	23	22	26	27	20	22	27	22	18	23	25	35	39	56	57
6	57	56	55	29	21	17	19	20	20	20	17	18	28	35	52	44	31	25	23	28	28	23	23	28	28	19	24	25	35	38	56	57
7	58	56	56	51	33	22	20	20	21	20	17	18	28	44	55	55	55	47	32	30	35	31	23	28	53	28	24	25	35	40	57	58
6	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	42	58	58

Link Number

key:

▩ <20 mph
▨ 21-40 mph
☐ > 40 mph

Table 4.10

Santa Monica Freeway
Comparison of Link Travel Times

Travel Times (seconds) for INTEGRATION

Time Slice	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	36	30	18	42	23	25	32	12	4	5	17	19	45	6	4	16	25	26	33	13	12	24	12	17	11	22	8	18	8	11	10	8
2	39	31	19	43	23	25	34	17	4	8	17	20	63	10	7	28	38	34	46	23	17	39	17	24	12	44	24	45	15	13	10	8
3	37	50	30	44	32	28	56	15	4	8	43	75	67	11	7	25	37	71	123	36	31	96	41	42	34	80	23	45	14	13	10	8
4	38	44	31	44	39	109	163	67	24	29	99	101	144	21	15	59	97	103	128	41	32	97	44	45	32	77	22	45	14	13	10	8
5	70	51	23	47	77	104	125	50	16	21	70	74	104	18	11	53	80	84	107	37	29	86	39	39	32	78	23	45	14	13	15	8
6	65	48	22	60	44	103	122	50	14	17	67	71	87	11	9	41	68	73	98	31	28	82	38	36	33	77	21	44	14	13	14	9
7	47	48	29	43	26	25	32	22	14	16	65	72	87	11	7	23	37	35	44	26	22	73	36	32	22	73	21	44	15	13	10	8
8	36	30	18	42	23	25	32	12	4	5	17	19	45	6	4	16	25	26	33	13	12	24	12	17	11	21	8	17	8	10	10	8

Link Number

Travel Times (seconds) for FREQ

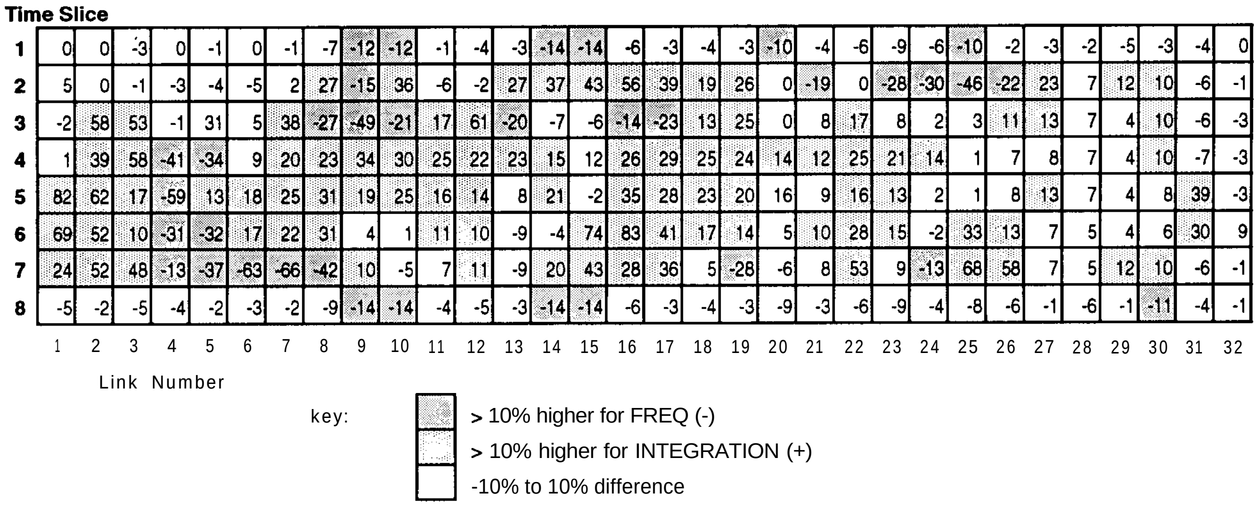
Time Slice	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	36	30	19	42	23	25	32	13	5	6	17	20	46	7	5	17	26	27	34	15	13	25	13	18	12	22	8	18	8	11	10	8
2	37	31	19	44	24	26	33	13	5	6	18	20	50	7	5	18	27	28	36	2:	21	39	24	34	22	56	20	42	13	12	11	8
3	38	32	20	44	24	27	40	21	8	10	37	47	84	12	7	29	48	63	98	36	29	82	38	41	33	72	20	42	13	12	11	8
4	38	32	20	74	59	100	136	54	18	22	79	83	117	18	13	47	75	82	104	36	29	78	36	40	32	72	20	42	13	12	11	8
5	38	32	20	115	68	88	100	38	13	17	61	65	96	15	11	39	62	68	89	32	27	74	35	38	32	72	20	42	13	12	11	8
6	38	32	20	87	65	88	100	38	13	17	61	65	96	12	5	22	48	63	86	30	26	64	33	37	25	68	20	42	13	12	11	8
7	38	32	20	50	41	68	95	38	13	17	61	65	96	9	5	18	27	33	62	28	20	48	33	37	13	46	20	42	13	12	11	8
8	38	30	19	44	24	26	33	13	5	6	18	20	46	7	5	17	26	27	34	14	12	25	13	18	12	22	8	18	8	11	10	8

Link Number

key:
- ▨ >100 seconds
- ░ 50-100 seconds
- ☐ < 50 seconds

Table 4.11

Santa Monica Freeway
Comparison of Link Travel Times



Time Slice	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0	0	-3	0	-1	0	-1	-7	-12	-12	-1	-4	-3	-14	-14	-6	-3	-4	-3	-10	-4	-6	-9	-6	-10	-2	-3	-2	-5	-3	-4	0
2	5	0	-1	-3	-4	-5	2	27	-15	36	-6	-2	27	37	43	56	39	19	26	0	-19	0	-28	-30	-46	-22	23	7	12	10	-6	-1
3	-2	58	53	-1	31	5	38	-27	-49	-21	17	61	-20	-7	-6	-14	-23	13	25	0	8	17	8	2	3	11	13	7	4	10	-6	-3
4	1	39	58	-41	-34	9	20	23	34	30	25	22	23	15	12	26	29	25	24	14	12	25	21	14	1	7	8	7	4	10	-7	-3
5	82	62	17	-59	13	18	25	31	19	25	16	14	8	21	-2	35	28	23	20	16	9	16	13	2	1	8	13	7	4	8	39	-3
6	69	52	10	-31	-32	17	22	31	4	1	11	10	-9	-4	74	83	41	17	14	5	10	28	15	-2	33	13	7	5	4	6	30	9
7	24	52	48	-13	-37	-63	-66	-42	10	-5	7	11	-9	20	43	28	36	5	-28	-6	8	53	9	-13	68	58	7	5	12	10	-6	-1
8	-5	-2	-5	-4	-2	-3	-2	-9	-14	-14	-4	-5	-3	-14	-14	-6	-3	-4	-3	-9	-3	-6	-9	-4	-8	-6	-1	-6	-1	-11	-4	-1

Link Number

key:

▨ > 10% higher for FREQ (-)

▤ > 10% higher for INTEGRATION (+)

☐ -10% to 10% difference

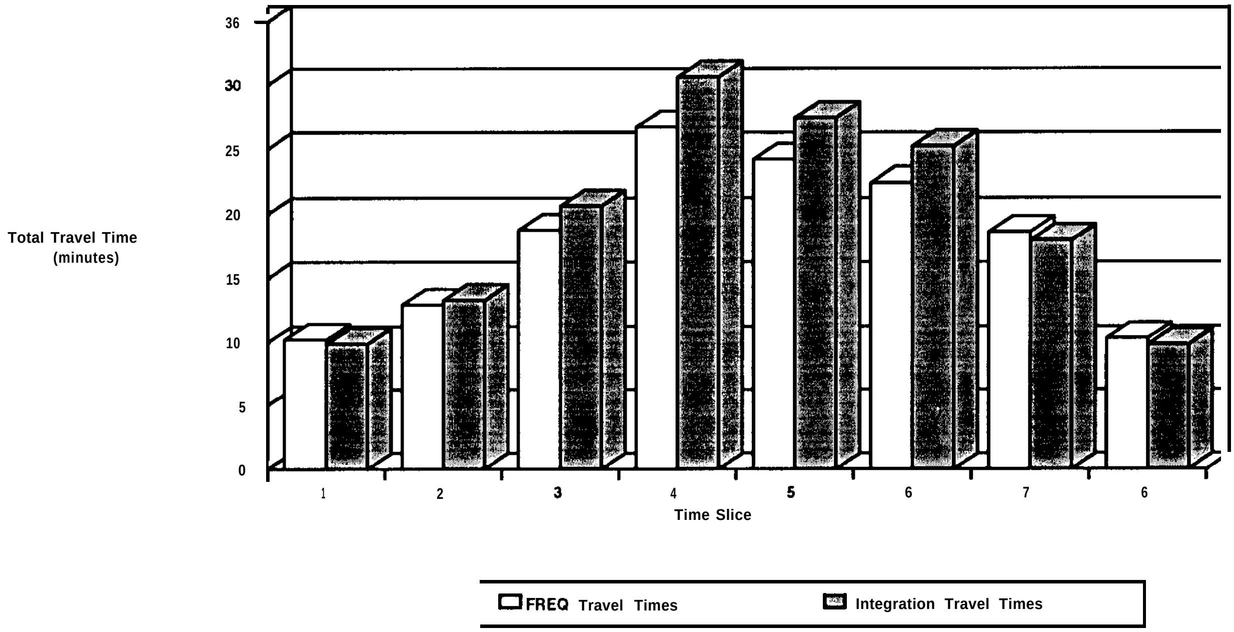


Table 4.12

Chapter 5: ATIS Modelling

5.1 INTRODUCTION

Chapter 4 of this report described the initial applications of the model with particular emphasis on freeway modelling. Another area of concern in the early stage of the model application was INTEGRATION 's response to the need for representing Advanced Traveler Information Systems (ATIS). INTEGRATION was presented by the model developers as a very special tool with unique features making it well suited to model ATIS. The intent was to focus on these specific features and become more familiar with the model's capabilities.

It should be noted that primary attention was given to dynamic route guidance information and the representation of dynamic route choice decisions; other aspects of ATIS such as static information for mode choice, departure time choice or destination choice are not considered in this study.

This chapter is divided into five sections, and the structure of the chapter is very similar to the one of Chapter 5. The most important requirements for ATIS modelling are identified and discussed in section 5.2. In section 5.3, the most important features of the INTEGRATION model that are directly related to ATIS modelling are described. The capabilities of INTEGRATION for ATIS modelling are then presented in section 5.4 through a case study called "Diamond Network Experiment". Section 5.5 provides an overall assessment of the study.

5.2 REQUIREMENTS FOR ATIS MODELLING

Traffic models to be used in ATIS applications require the ability to determine the paths followed by drivers between their origins and destinations, and to examine the actual travel time experience of these drivers as they follow the selected paths. Therefore, it is necessary to combine both traffic flow simulation with traffic assignment capabilities.

The simulation model must be able to handle networks of sufficient size and with sufficient level of detail to model various types of network and control features. A critical aspect is the need for realistic modelling of traffic performance in conditions of time-varying traffic demand (including congestion effects). The modelling of traffic variability and, in particular, traffic incidents and their characteristics (location, severity and duration) is also a needed feature.

In terms of routing behavior, there is a need to represent the route choice of both equipped (drivers with ATIS) and unequipped drivers. A very important aspect is the fact that the routing assignment is also represented as a dynamic process: the attractiveness of competing routes may vary during the study period, due to the variation in time of origin-destination demand and the variation of the network supply. Furthermore, the attractiveness of competing routes may even change while a vehicle is en-route.

Many spatial/temporal factors need to be modelled when dealing with ATIS, such as the location and operation of the detectors which collect traffic information and the roadside beacons which communicate route recommendations. The model must be able to represent vehicles moving in space and time through the network.

It is necessary to take into account the dynamic nature of the driver's path choice decisions in response to the supplied real-time in-vehicle information. There is a need to simulate driver's response to incidents and the effects of ATIS on this behavior. In particular, aspects like the driver/on-board equipment interface, the driver's compliance with the information provided and the general credibility of the system, are likely to affect the assessment of ATIS and therefore, need to be modelled.

5.3 INTEGRATION CAPABILITIES FOR ATIS MODELLING

For a general overview of the INTEGRATION model, the reader should refer to Chapter 3 of this report, or to the Model User's Guide [18]. This section focuses on the model's characteristics which are directly related to ATIS modelling. Specific references to the use of INTEGRATION in IVHS applications can be found in references [15], [19], and [28].

The INTEGRATION model considers the behavior of traffic flow in terms of individual vehicles that can be configured to have self-assignment capabilities. The model is not based on an explicit time-slice approach; rather, it assigns individual vehicles sequentially to a network that is already loaded with any previous departures that have not reached their destination. At each node, vehicles select which link to follow next to reach their desired destination based on the latest available minimum path tree. The model's consideration of individual vehicles is primarily for improving the analysis resolution during the model's internal calculations and in order to track individual vehicle paths and statistics. However, it does not necessarily require the user to collect or input data at the individual vehicle level. Instead, traffic flow characteristics and traffic demands can be specified by the user at an aggregate or macroscopic level, leaving it to the model routines to derive the more microscopic measures for each individual vehicle.

The model has the ability to represent combined freeway and arterial networks which experience time-varying congestion. INTEGRATION reflects the most important attributes of congestion through its explicit account of queue growth/delay while maintaining a dynamic equilibrium traffic assignment. The explicit account of queue size and delay through the tracing of individual vehicles permits direct modelling of queue spill-back from upstream links, continuous modelling of traffic signal progression, and automatic delay of downstream link arrivals if they are held up at an upstream bottleneck. In addition, as the relative travel time between the shorter (but congested) route and a longer (but less congested) route changes, new arrivals can be allowed to automatically redistribute themselves to avoid the congested link or area.

The INTEGRATION model allows the analyst to specify traffic flows in terms of any combination of five different driver/vehicle types. These different vehicle types are not intended to represent trucks, buses, or passenger cars, as would be the case in most other models. Instead, they refer to the capability to represent different routing behavior or different access privileges to real-time travel time information for each vehicle. Driver/vehicle types 1 and 2 have attributes that make them well suited to represent various forms of likely behavioral rules for equipped and unequipped drivers/vehicles. The attributes of driver/vehicle types 1 and 2 are directly related to

ATIS modelling and will be discussed next; for a description of the attributes of driver/vehicle types 3,4,5 the reader can refer to the User's Guide [18].

Driver/vehicle type 1 is typically considered to represent a vehicle without access to real-time traffic information. This type of driver/vehicle will be referred as "unguided" traffic in the rest of the report. It can be assigned routings based on externally specified path trees. It is possible in this mode to provide more than one path tree for each destination, where each tree has its own probability of being selected. Alternatively, INTEGRATION can calculate path trees for driver/vehicle type 1 internal to the model, based on an externally specified time series of anticipated travel times on the network. The provision of such travel times can be considered as providing vehicle type 1 drivers with access to a time series of historic link travel time information. If no external path trees or historic data are provided, the model will automatically calculate default path trees based on a stochastic sampling of free flow link travel times. The latter internal route path calculations are carried out at user specified intervals with a specific link travel time error term.

It can be seen that a lot of different routing strategies are available for the type 1 driver. Under some of these strategies, drivers may be modelled as having less information than they would ordinarily possess in real-life through radio traffic information or direct observation of immediate surroundings.

Driver/vehicle type 2 is provided with virtually continuous updates of real-time link travel times throughout the simulation. Such travel time updates are provided at each node or at selected nodes, and at user specified intervals. These vehicles can be used to model the behavior of vehicles within various forms of dynamic route guidance systems.

5.4 DIAMOND NETWORK EXPERIMENT

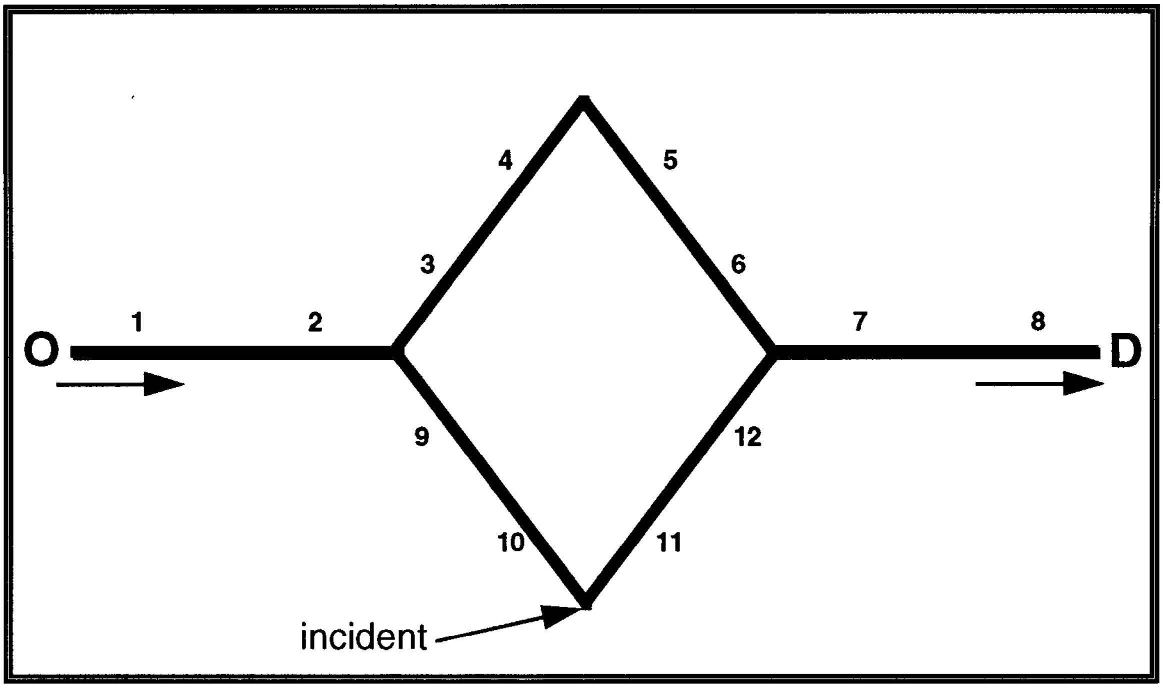
The main purpose of the Diamond network experiment was to test and illustrate various fundamental features of the INTEGRATION model related to ATIS investigations prior to full application to the Smart Corridor. A theoretical network, called the Diamond network, was coded for this application. The simple design of the Diamond network allowed the analyst to observe and understand the basic processes occurring during the simulation without the complication of unnecessary details. It also provided a convenient test case for INTEGRATION's reliability as well as training for the user before analysis of more complex networks.

54.1 Design of Experiment

a. Network

The simulated Diamond network is shown in Figure 5.1. The basic network is symmetric with the top and bottom routes having the same length and the same capacity. All other things being equal, the travel time over both routes are the same. Links 1 and 2, which are located next to the origin node, are each 1.2 miles long with 4 lanes and a capacity of 2000 veh/hr/lane. When the road splits at the end of link 2 there are two lanes going to the north and two lanes to the south with the same lengths and the same capacities per lane as links 1 and 2. The two roads join back

Diamond Network



NETWORK

Subsection Number	Length (miles)	Number of Lanes	Capacity (veh/hour)
1	1.24	4	8000
2	1.24	4	8000
3	1.24	2	4000
4	1.24	2	4000
5	1.24	2	4000
6	1.24	2	4000
7	1.24	4	8000
8	1.24	4	8000
9	1.24	2	4000
10	1.24	2	4000
11	1.24	2	4000
12	1.24	2	4000

INCIDENT

Link 10
1.5 lanes blocked (t=15 min to 30 min)
1.0 lanes blocked (t=30 min to 45 min)

DEMAND

5000 vehicles/hour (t=0 min to 60 min)
0 to 100% guided vehicles

Figure 5.1

together at links 7 and 8 just before the destination node. Links 7 and 8 are the same as links 1 and 2 with lengths of 1.2 miles each and capacities of 2000 veh/hr/lane. The total distance from origin to destination by either route is 9.6 miles.

Every node represents a point in the network where routing decisions are made for each guided vehicle, based on link travel time information from that node to the vehicle's destination. For this reason, these nodes can be thought of as representing Route Guidance System (RGS) beacons that both collect information from equipped vehicles regarding the travel time over the last traversed link, as well as update equipped vehicles with the latest estimate of the minimum path tree (quickest route to the destination). In the Diamond network all the beacons are spaced at 1.2 mile intervals. The significance of beacon placement will be discussed later.

b. Quality of Information

The quality of trip time information provided to guided vehicles in the INTEGRATION model can be controlled by two parameters: the update information frequency and the distortion factor. These parameters have to be determined or calibrated when the user intends to replicate the workings of a specific RGS. As described later, it was found that these two parameters have a very strong impact on the simulation results, and that special attention has to be given in selecting appropriate values for these parameters.

The update information frequency represents the time interval at which the link travel times used in the minimum path tree calculations are updated. It can be set to 0 (for no update), or made to vary from 1 to 9000 seconds. The model considers only current travel times and does not allow for estimations of future travel times.

The distortion factor is the amount of error (or noise) that is introduced into the real-time link travel time data prior to tree building. Before any routing updates are made, based on new link travel time estimates, a normally distributed error is introduced into the actual travel times on a link by link basis. The user can specify the magnitude of the error as a percentage of the mean link travel time. This error term is intended to serve several purposes. First, it can be used to reflect the well-known fact that drivers and for that matter ATIS do not always have perfect link travel time information. Specifically, even vehicles equipped with RGS are likely to be provided with somewhat distorted travel time information inherent to any system relying on dynamic data collection. Secondly, the error term can be used as an indirect way of reflecting the fact that all the equipped drivers do not always comply with the routing provided by the on-board guidance system. In addition, the error term provides INTEGRATION with the ability to incorporate a stochastic loading model, which prevents all guided vehicles from choosing or loading onto the same route.

c. Incident

An incident was introduced at the downstream end of link 10 (see Figure 5.1) of the Diamond network to cause queues (and therefore make alternative route travel times unequal) giving guided vehicles a reason to divert to a faster route. Without the incident there is no reason for guided and unguided vehicles to behave differently. They would split evenly between the top and bottom routes. Under incident conditions, it was assumed that unguided vehicles would be unaware of the incident and would distribute themselves evenly between the two routes as before. The choice of incident severity will be discussed later for each scenario.

d. Demand

Given the capacities of the links, a demand rate of 5000 veh/hr was chosen to flow through the network for a one hour period. This demand rate ensured that without an incident there would be no queuing, because the demand never exceeds the capacity. Also, as previously noted, without an incident both guided and unguided vehicles will split evenly between the top and bottom routes, giving a demand of 2500 veh/hr on both routes. However, the demand rate ensured that if one lane were blocked on any part of the network, leaving a capacity of 2000 veh/hr, a queue would form because the demand would exceed capacity by 500 veh/hr.

e. Rate of Guided Vehicles

An important part of this study was to observe the performance of the system at different levels of market penetration. Market penetration refers to the percentage of vehicles on the road that are both receiving and are acting upon route guidance information supplied through ATIS. Equipped vehicles were coded as driver/vehicle type 2 within INTEGRATION, whereas other vehicles were coded as driver/vehicle type 1.

The percentage of guided vehicles was varied from 0 to 100% at 5% intervals. For each level of market penetration, the overall system performance was evaluated as well as the performance of guided and unguided vehicles. Measures of performance such as total vehicle hours of travel time and average trip time were used in the analysis.

5.4.2 Results of the Experiment

Five basic scenarios were simulated to investigate the effect of ATIS on the traffic flows through the Diamond network. The scenarios were altered by changing incident severity, the quality of trip time information (distortion factor) and the density of RGS beacons. In all five scenarios, the simulation period was one hour long, the demand was 5000 veh/hr, the incident occurred on link 10, the update rate for the minimum path tree provided to guided vehicles at beacons was one second, and the rate of guided vehicles was varied from 0 to 100%.

a. Scenario 1

In Scenario 1 the incident introduced into the network was the following:

1.5 lanes blocked from t = 15 min. to t = 25 min.
0.5 lanes blocked from t = 25 min. to t = 35 min.

This was considered to be a moderately severe incident because it takes ten minutes to partially clear it from the road and then ten more minutes to completely remove it.

The trip time distortion, which determines the quality of information provided to equipped vehicles (as described in paragraph 5.4.1.b), was set to 20% for this scenario. It means that the magnitude of the error introduced in the link travel time information provided to the guided vehicles was 20% of the mean link travel time. For example, for a link that has an average travel time of 1 minute, the perceived link travel time is a random variable that is normally distributed with a mean of 1 minute and a variance of 0.2 minutes. This distortion was intended to represent the natural variations in trip time data provided by the information infrastructure as well as the fact that users of the system will not always follow the route provided by the route guidance system.

There were only small benefits to route guidance for this scenario. Figure 5.2 shows the effect of market penetration in terms of average trip time. The average trip time decreased from about 11.6 minutes (0% guided vehicles) to an optimum of 11.2 minutes for all vehicles at a market penetration of 45%. This is an improvement of only 3.5%. Figure 5.3 shows the effect of market penetration in terms of total travel time for the system.

Beyond the optimum level of market penetration, the performance of the whole system began to degrade both in terms of average trip time and total system travel time. The system actually performed worse at the highest levels of market penetration than it did with no guided vehicles. These results were not expected and further investigations to address this problem will be described in Scenarios 2 and 3.

An interesting observation is that at low levels of market penetration (e.g. 5%) the benefits to guided vehicles are the greatest from a user perspective (see Figure 5.2). For instance, at the 5% level of market penetration guided vehicles have an average trip time of 10.9 minutes while unguided vehicles take an average of 11.5 minutes.

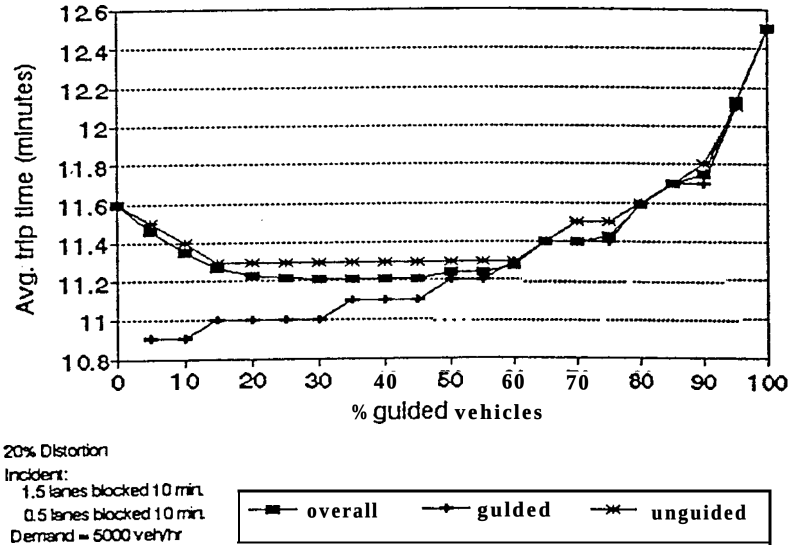
Therefore, at low levels of market penetration the incentive for an individual to purchase a route guidance system is the greatest. At a market penetration level of 5%, one driver can save 0.6 minutes of travel time by purchasing the route guidance system. By doing so, the driver improves his travel time, the average travel time of unguided vehicles, and the average travel time for the whole system. This purchase, though, slightly degrades the performance of guided vehicles. As shown in Figure 5.2, the average trip time of guided vehicles slightly increases with the level of market penetration.

Eventually, as more drivers switch to route guidance, there is very little difference observed between the performance of guided and unguided vehicles, and the incentive to purchase a route guidance system is greatly diminished. The reasons for this are that subsequent guided vehicles receive less benefit as more vehicles find the better route, and as guided vehicles switch, the remaining unguided vehicles experience lower travel time.

b. Scenario 2

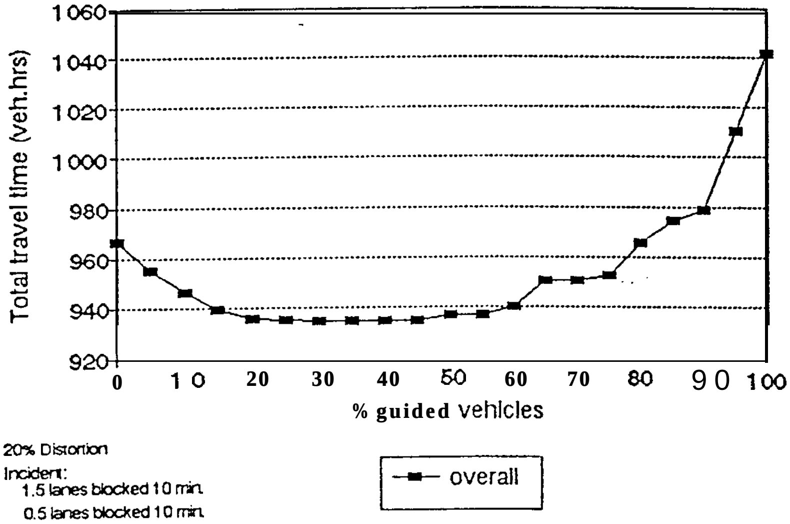
The motivation for creating Scenario 2 was to determine if a more severe incident would yield greater benefits for route guidance systems and to look for the reason behind the deterioration of the system at high levels of market penetration in Scenario 1.

Figure 5.2
Scenario 1: User Benefits



20% Distortion
Incident:
1.5 lanes blocked 10 min.
0.5 lanes blocked 10 min.
Demand = 5000 veh/hr

Figure 5.3
Scenario 1: System Benefits



20% Distortion
Incident:
1.5 lanes blocked 10 min.
0.5 lanes blocked 10 min.
Demand = 5000 veh/hr

The incident introduced into the Diamond network for this scenario was the following:

1.5 lanes blocked from t = 15 min. to t = 30 min.
1.0 lane blocked from t = 30 min. to t = 45 min.

This incident is more severe than the incident in Scenario 1. It lasts a total of ten minutes longer and more of the road is blocked.

The trip time distortion for this scenario was reduced to 5% in an attempt to address the problem of the deterioration of the system performance at higher levels of market penetration.

There were greater benefits to route guidance under this scenario than for Scenario 1. There was a 17.6% decrease in average trip time at the optimum level of market penetration (45%). Figures 5.4 and 5.5 illustrate the performance of the system at different levels of market penetration in terms of user benefits and system benefits.

The same overall patterns were observed in this scenario as were observed in Scenario 1, such as decreasing benefits to guided vehicles at higher levels of market penetration, and rapid deterioration of system performance beyond about 60% guided vehicles.

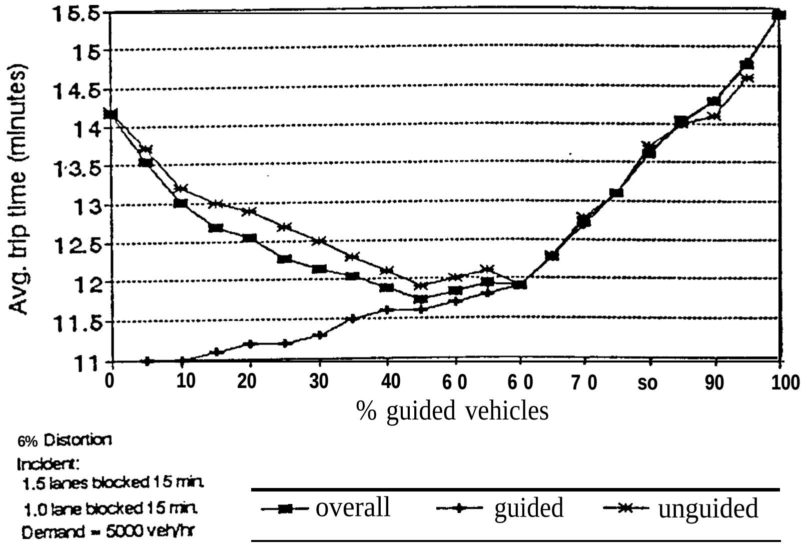
The INTEGRATION graphics were used in Scenario 2 to determine why the system began to degrade, and degrade so quickly, at higher levels of market penetration. The on-screen animation allowed observation of platoons of guided vehicles that would form after the incident was cleared and continue until the end of the simulation period.

This disequilibrium in the system began immediately after the congestion resulting from the incident on the bottom route was cleared. At this time a platoon of guided vehicles would take the bottom route until it was congested. All the guided vehicles would then take the top route until it was congested and then begin taking the bottom route again. This process would repeat itself until the end of the simulation run and showed no signs of diminishing.

It was hypothesized that because the information that was provided to vehicles was not continuous (only provided at nodes at every 1.2 miles) and was based only on the reported trip times of vehicles that had just finished traversing a link, route guidance would cause vehicles to act this way. If for example, there was a queue on a link, this would not be reported to vehicles behind the queue in the form of travel time information until the vehicles affected by the queue reached the next node. Meanwhile, vehicles would continue entering the link with a queue making the system perform worse.

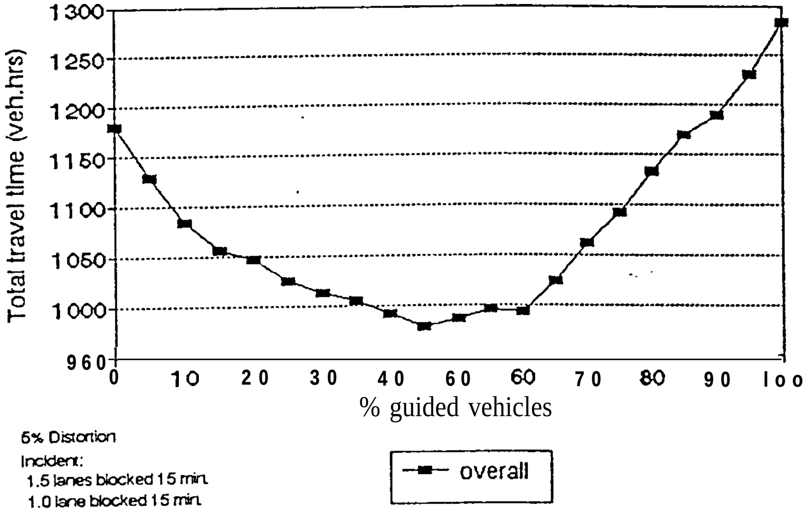
It should also be noted that the feedback oriented vehicle type 2 (guided vehicles) can reproduce an equilibrium to a less accurate level than vehicle type 1 (unguided vehicles). Therefore, while vehicle type 2 benefits during incidents, it has a poorer travel time experience under non-incident conditions following congestion. The combination of both a longer and a more severe incident in Scenario 2 vs. Scenario 1 were both in favor of guided vehicles.

Figure 5.4
Scenario 2: User Benefits



6% Distortion
Incident:
1.5 lanes blocked 15 min.
1.0 lane blocked 15 min.
Demand = 5000 veh/hr

Figure 5.5
Scenario 2: System Benefits



6% Distortion
Incident:
1.5 lanes blocked 15 min.
1.0 lane blocked 15 min.
Demand = 5000 veh/hr

c. Scenario 3

Scenario 3 was developed to test the hypothesis about the cause of the rapid deterioration in system performance at high levels of market penetration. If the hypothesis made in interpreting the results of Scenario 2 were true, then increasing the distortion in trip time information would disperse the platoons and improve the performance of the system.

Scenario 3 had the same characteristics as Scenario 2 except that the trip time distortion on each link was increased to 50%.

At the optimum performance level for Scenario 3, the improvement in average trip time for all vehicles was about the same as for Scenario 2. The difference, though, with Scenario 3 was that the optimum occurred at 65% market penetration rather than 45% and there was much less deterioration in system performance at the high levels of market penetration. Figures 5.6 and 5.7 show the average trip time (user benefits) and total travel time (system benefits) for Scenario 3.

Figure 5.8 shows a comparison of average trip time at varying levels of market penetration for Scenarios 2 and 3. This figure illustrates the dramatic difference in system performance at the high levels of market penetration caused by different trip time distortion levels.

The significance of Scenario 3 is that for all levels of market penetration the system performs better than if there were no guided vehicles. It also supports the hypothesis that was made in interpreting results of Scenario 2 regarding the cause of the rapid deterioration in system performance at high levels of market penetration. This indicates that there are steps that can be taken at high levels of market penetration to avoid the system deterioration.

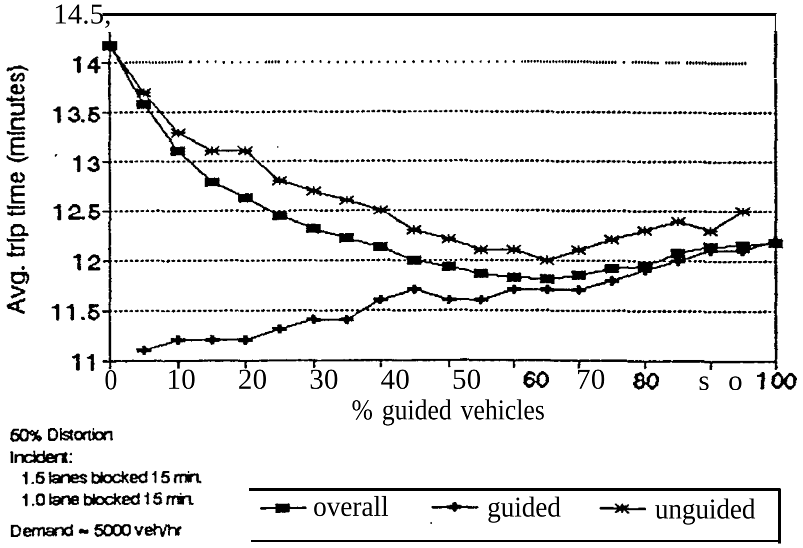
d. Scenarios 3a and 3b

To further understand the effects of trip time distortion and its significance at higher levels of market penetration, two additional scenarios (3a and 3b) were considered where the level of distortion was varied but not the level of market penetration.

These two scenarios had the same characteristics as Scenario 3. In Scenario 3a, the level of market penetration was 80% and the average trip time was determined for levels of distortion varying from 0 to 100%. The results were as expected with dramatic improvement in average trip time as the amount of distortion was initially increased reflecting the dispersion of the platoons of guided vehicles (see Figure 5.9). The results also showed that beyond 50% distortion there was very little improvement in average trip time.

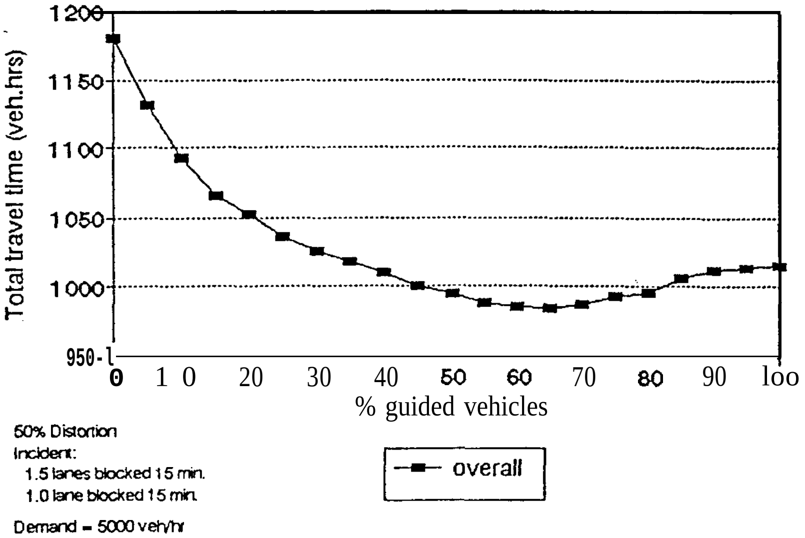
In Scenario 3b the level of market penetration was 25%. The results for this scenario showed that at lower levels of trip time distortion the system performed better (see Figure 5.9). This reflected the fact that there was not a platooning problem in the low level of market penetration and that the distorted information was serving only to degrade the system and not disperse platoons.

Figure 5.6
Scenario 3: User Benefits



50% Distortion
Incident:
1.5 lanes blocked 15 min.
1.0 lane blocked 15 min.
Demand = 5000 veh/hr

Figure 5.7
Scenario 3: System Benefits



50% Distortion
Incident:
1.5 lanes blocked 15 min.
1.0 lane blocked 15 min.
Demand = 5000 veh/hr

Figure 5.8
Effect of trip time distortion

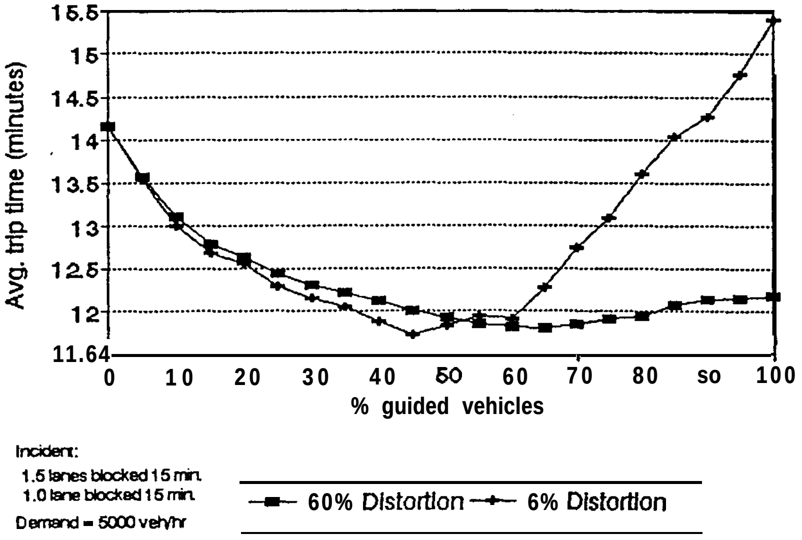
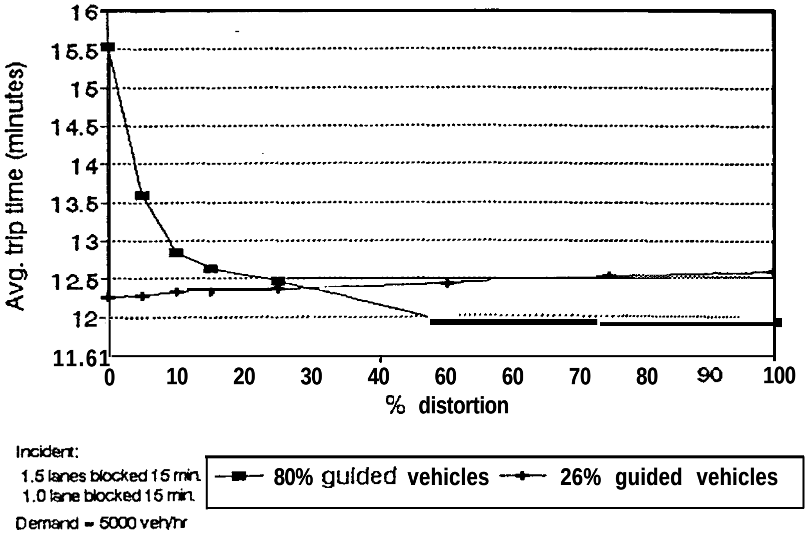


Figure 5.9
Scenarios 3a and 3b



e. Scenarios 4 and 5

Two additional scenarios were considered to further address the problem of system deterioration at high levels of market penetration. As described earlier, the information provided to the guided vehicles in the INTEGRATION modelling approach is available only at each node of the coded network. Every node in the network represents a point where routing decisions are made.

All the scenarios described so far were based on the same network file consisting of nodes located every 1.2 miles. The purpose of Scenarios 4 and 5 was to test the effect of using a network in which the nodes would be located every 0.3 miles. The new scenarios represent a network with higher RGS beacon density. The overall distance from the origin to the destination, however, remains unchanged.

The incident characteristics of Scenarios 4 and 5 are the same as for Scenarios 2 and 3. The only difference between Scenarios 4 and 5 is the distortion factor. It is set to 5% in Scenario 4 (as in Scenario 2) and to 50% in Scenario 5 (as in Scenario 3).

Figures 5.10 and 5.11 show the system benefits of ATIS using the new network characteristics (higher RGS beacon density), in comparison to those obtained in Scenarios 2 and 3 with the initial network configuration. Figure 5.10 illustrates that the higher beacon density used in Scenario 4 has a slightly favorable impact on the average trip time at high levels of ATIS market penetration. However, this positive impact does not solve the problem of the deterioration of system performance for high levels of ATIS market penetration, In Scenario 5 (see Figure 5.11), it appears that using a higher beacon density does not have a significant impact on the overall performance of the system.

Scenarios 4 and 5 show that using a higher beacon density network slightly improves the performance of the system for high levels of market penetration. However, the effects of this parameter appear to be less significant than the effects of the trip time distortion factor.

5.5 CONCLUSIONS

Prior to full application to the Smart Corridor, the INTEGRATION model has been applied to a number of different traffic demand-supply networks in order to test the validity of the model and to evaluate various model parameters. A simplified and hypothetical "Diamond" network was chosen in order to evaluate the ability of the model to realistically simulate route choice decisions associated with ATIS.

Simulation runs, referred to as scenarios, were undertaken with the INTEGRATION model being applied to the Diamond network. A number of model parameters were evaluated and user and system benefits of a number of scenarios were assessed. The conclusions reached in regard to the model parameters and user/system benefits are summarized in the following paragraphs. While the results were obtained for a very specific network and traffic pattern, it appears that some of the findings should also be valid for more general conditions.

The model parameters evaluated included incident severity, percent guided vehicles, travel time

Figure 5.10
Scenario 4: Effects of Beacon Density

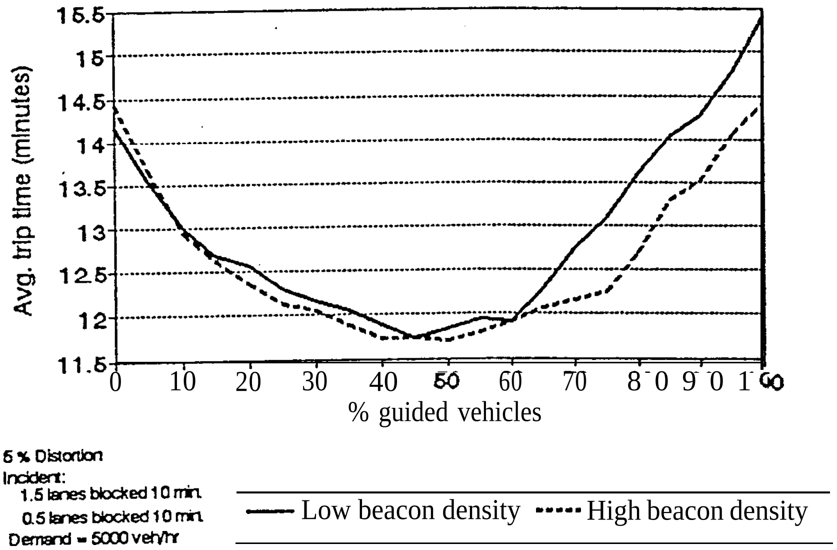
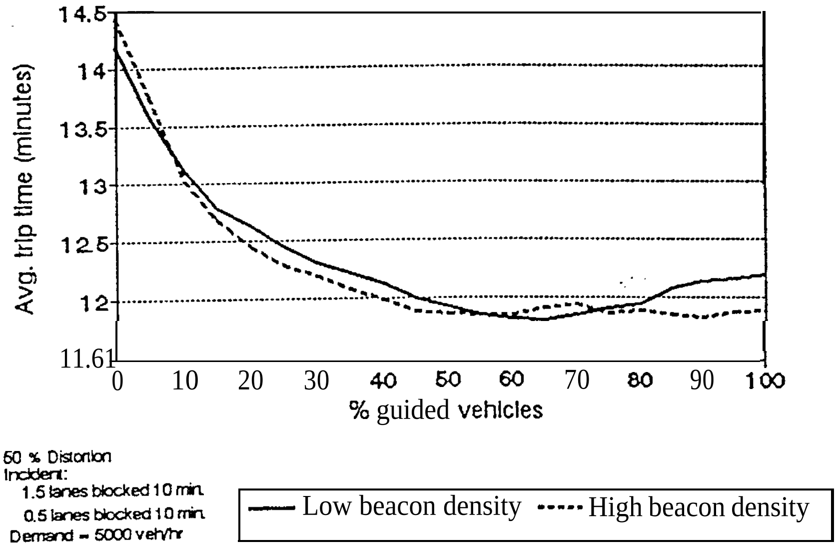


Figure 5.11
Scenario 5: Effects of Beacon Density



distortion, and beacon spacing. Benefits were greatest under the more severe incident situations and with smaller intervals between beacons. The percent guided vehicles and travel time distortion model parameters were more complex to evaluate, and had significant effects on user and system benefits of ATIS.

When the percent guided vehicles were small, on the order of 0 to 15%, the guided vehicles obtained the most significant reduction in travel time, and the total system travel time was significantly reduced. Travel time distortion and beacon spacing were not significant factors.

As the percent guided increased, from 15% to some mid-range percentage, such as 40 to 60%, the travel time of guided vehicles began to increase while both the travel time of unguided vehicles and the total system travel time continued to decrease to their minimum values. At the mid-range percentages of guided vehicles, the differential between travel times of guided and unguided vehicles became insignificant.

When the percentage of guided vehicles exceeded 40 to 60%, the travel time of both guided and unguided vehicles increased and were almost identical, while the total system travel time significantly increased. These adverse effects on both guided and unguided vehicles could be reduced by increasing the travel time distortion and reducing the beacon spacing. It is quite possible, though, that in practice high levels of market penetration will never be reached because of the decreasing benefits to each additional purchaser of a route guidance system. These concerns would become important, though, if route guidance systems were provided as standard equipment in all vehicles that are manufactured.

In summary, a great deal was learned about model parameters, their effect on user and system benefits, and their appropriate settings. The INTEGRATION model proved to be a very useful tool for this type of application, because the model has the capability to represent different routing behaviors based on different access privileges to real-time information for each vehicle. However, some limitations were identified when testing the modelling of ATIS. First, only en-route type of information was considered in this study. The modelling of vehicles without access to ATIS is not always as realistic as it could be, especially when considering that these drivers can always observe traffic conditions of immediate surroundings or listen to radio traffic information. Also, the realism of the model predictions under high levels of ATIS market penetration was found somewhat questionable under some specific network-demand conditions. One explanation was that the routing of the guided vehicles is always based on the current link travel times, and the model is not capable of estimating the impact of the routing decisions on the future link travel times. Another area of potential improvement is the representation of driver’s behavior aspects in response to ATIS information, particularly the expected level of compliance.

Chapter 6: Smart Corridor Application - Reference Base Assignment

6.1 DESIGN OF EXPERIMENT

With the goal of determining the potential benefits of ATIS in a real-life freeway/arterial network, an, experiment was designed to model a portion of the Smart Corridor with the INTEGRATION model. The first step of the experiment was to develop a reference base assignment that as closely as possible represented the Smart Corridor under typical morning peak traffic conditions. The remainder of this chapter is devoted to a discussion of this process.

The development of the reference base assignment involved three major phases.

- the coding of the network and control;
- the demand estimation;
- the calibration (or validation) of the base conditions.

6.2 NETWORK CONFIGURATION AND CODING

The network which was used in the Smart Corridor investigation is shown in Figure 6.1. This network, which is part of the Smart Corridor in Los Angeles, involves about nine miles of the Santa Monica Freeway, and two parallel arterials: Washington Boulevard and Adams Boulevard. Also included in the network are nine major north-south streets (Hoover, Vermont, Normandie, Western, Arlington, Crenshaw, LaBrea, Fairfax and LaCienega) connecting Adams, Washington and the freeway. LaCienega Boulevard (West) and the Harbor Freeway (East) form the boundaries for the network.

The coding of the network for use in INTEGRATION involved giving a detailed description of the physical features of the network and the nature of the controls, as described in section 3.2 of this report:

- Node coordinates: used for graphic display in INTEGRATION and to define origin/destination nodes and internal nodes;
- Link characteristics: location (node from-node to), length, number of lanes, free flow speed, saturation flow rate, type of control;
- Traffic signals: list of all traffic signals on the network, signal timing information and time during which traffic signal plan is applicable.

Most of the information required for the coding of supply and control data was obtained from previous studies conducted at ITS which used the Smart Corridor in their investigations (ref. [3] and [5]). The information was generally in the form of FREQ and TRANSYT input data files

Plot of Network Modelled

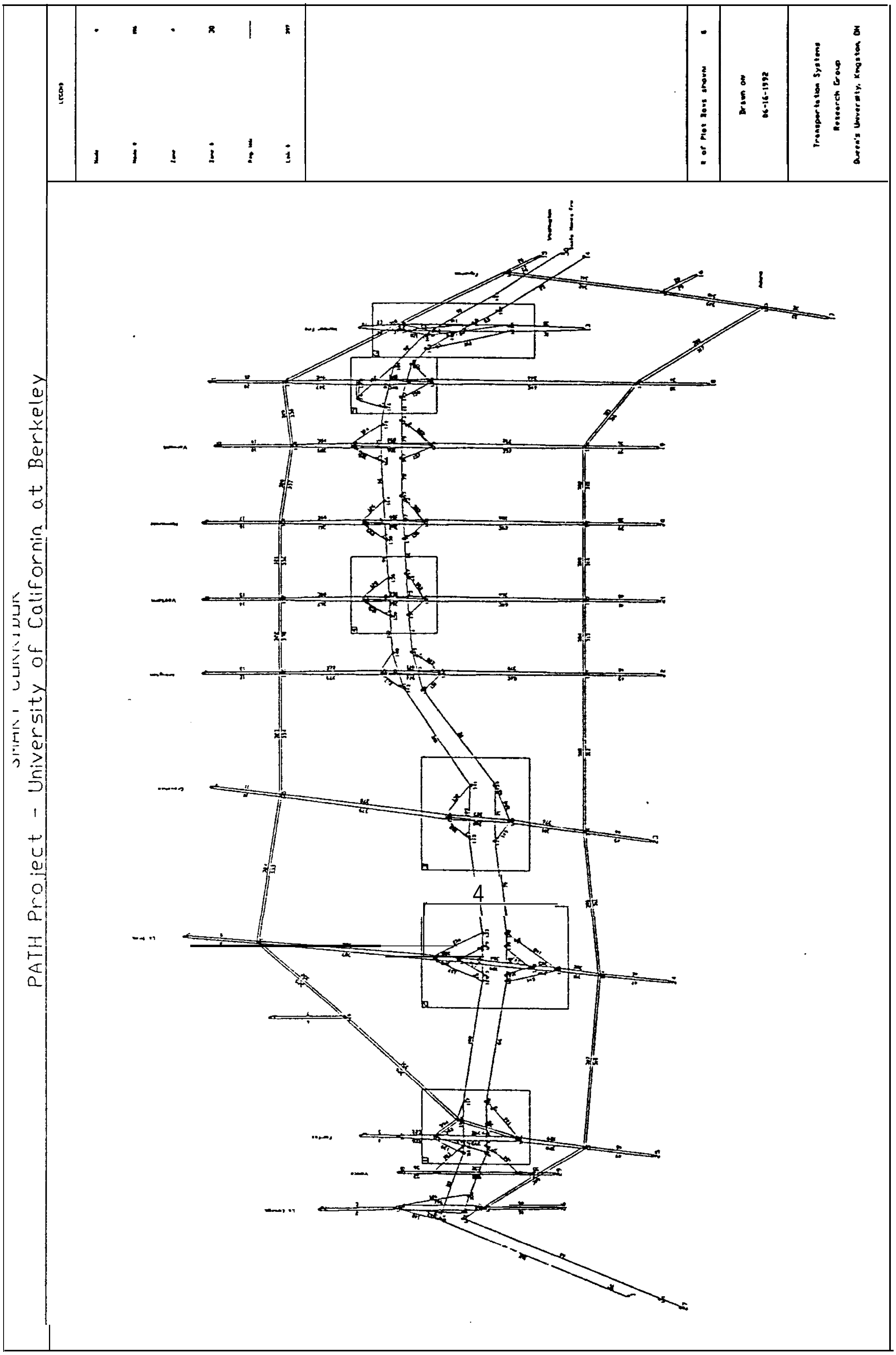


Figure 6.1

based on earlier information provided by the city of Los Angeles and Caltrans. Additional information was also obtained, when needed, from Caltrans and the City of Los Angeles.

The set of node coordinates obtained from previous projects was modified using a new set of axes centered on the Washington Blvd - Venice Blvd intersection. The reason for this modification was to make it possible for any scaled map of the area to be used should any expansion or modification of the network be necessary. A further modification of the coordinates was performed to improve the visual appearance of the network.

It also became necessary after the first initial runs of the model to put additional nodes at the interchanges and intersections adjacent to the Santa Monica Freeway. This was done in part to:

- isolate the left turning movements so that they could be assessed penalties to reflect the delays they normally incur;

- reduce the number of drivers using the ramps to bypass sections of the freeway;

- set the stage for the consideration of ramp metering should it become necessary for the investigation to include this aspect.

A depiction of how the interchanges were dealt with is shown on Figure 6.2. This special treatment of the intersections to reflect delays incurred by left-turning movements was not extended to intersections on Washington and Adams Boulevards, mainly because of a time constraint. This will, however, have to be addressed in any further investigations on this network in order to improve the quality of the simulation.

The coding for ramp metering required that the on-ramps be coded as two links, with the traffic signal located at the middle node (see Figure 6.2). If no metering is necessary, the traffic signal is set at 100 percent green time; otherwise the signal timings are set accordingly. No ramp metering was considered for this part of the investigation.

Figure 6.3 illustrates the coding of six interchanges of the modelled network. These plots as well as the plot of the entire network shown in Figure 6.1 were derived from the node coordinate and link data files, with the INTMAP program developed at Queen's University to produce plots of networks used in INTEGRATION (see paragraph 3.4.7).

The number of links on the coded network is 308 (60 uncontrolled freeway links, 60 ramp links and 188 arterial and major street links). Free flow speeds were set at 104 km/h (65 mph) on freeways, 80 km/h (50 mph) on arterials and major streets; and varied on ramps to limit irrational movements of motorists. Link capacities, lengths and number of lanes were as they appear in FREQ and TRANSYT input files. Links for the left-turning movements were assigned special characteristics to reflect delays incurred by these movements : length set at 500 m, saturation flow set at 1200 vehicles per hour of green per lane, and free flow speeds set at 50 km/h (35 mph).

The signal timing data were taken from TRANSYT input files based on data from the City of

Detail of Interchange Coding

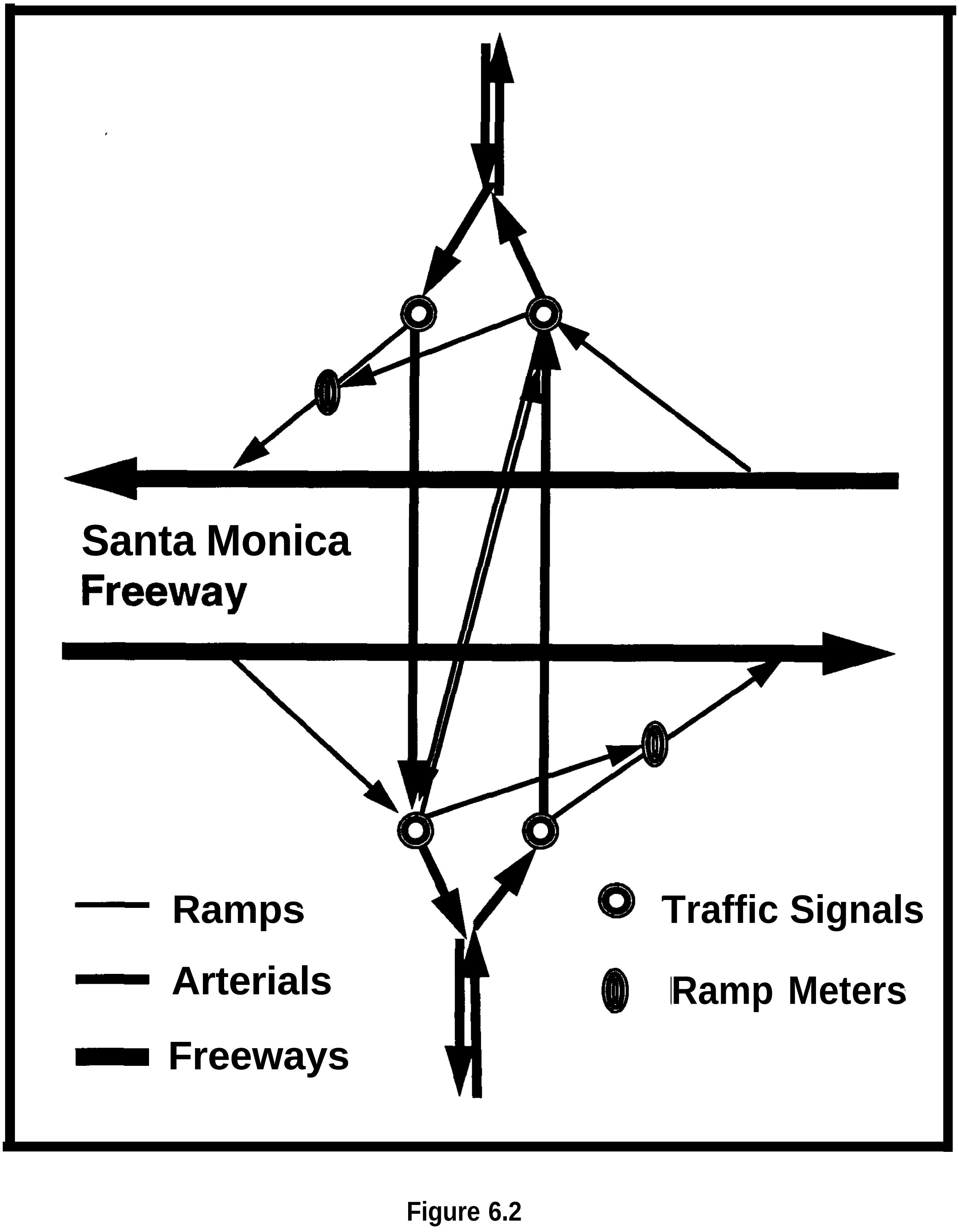


Figure 6.2

Plots of Six Modelled Interchanges

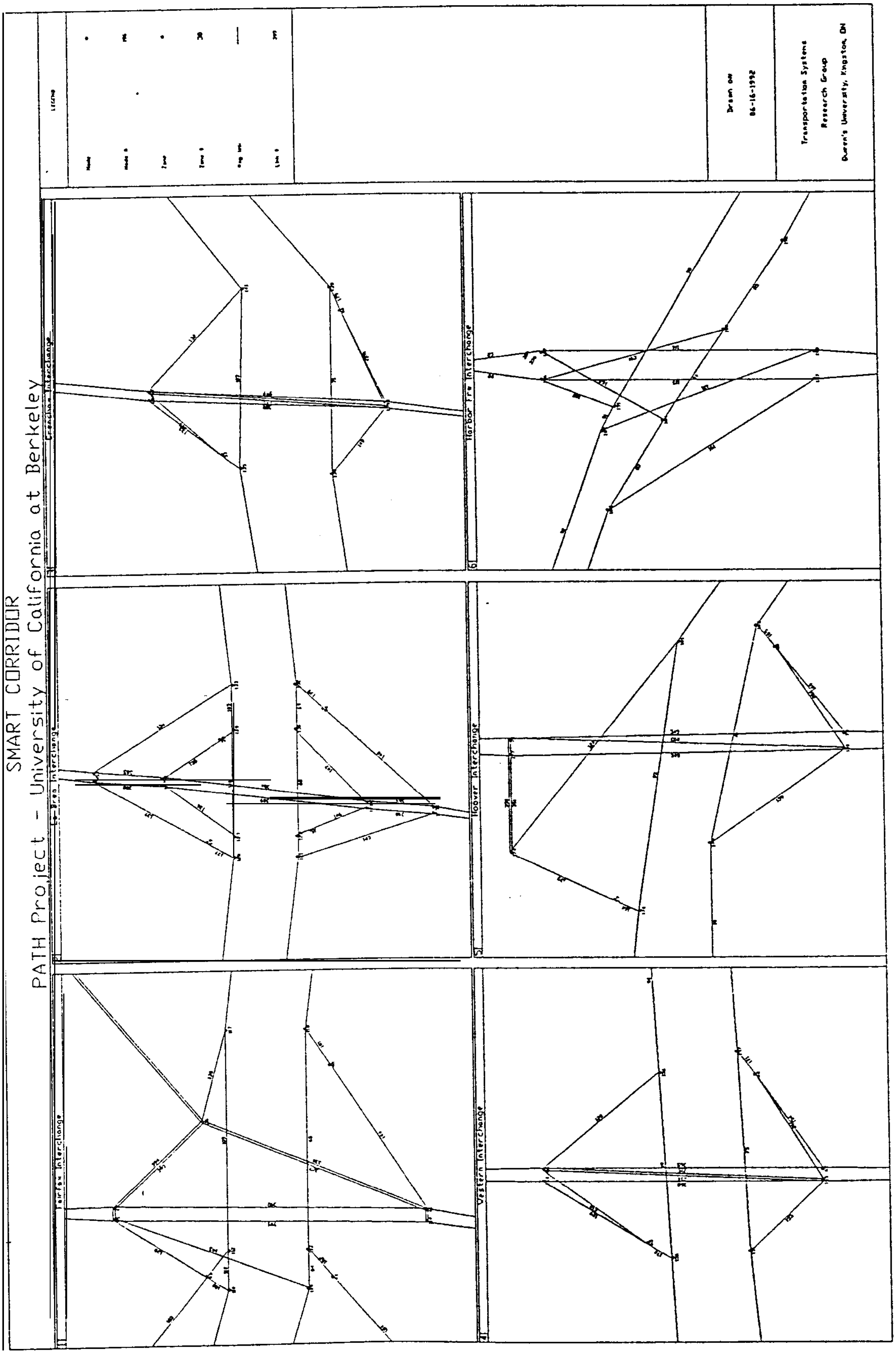


Figure 6.3

Los Angeles. Most of the traffic signals were coded with fixed-time signal timings. However, as will be described in Section 6.4, it was found necessary to optimize the timings of the traffic signals controlling the freeway off-ramps in order to more realistically simulate field conditions. This optimization was made using the technique described in paragraph 3.2.3 (local optimization).

6.3 DEMAND ESTIMATION

6.3.1 The Demand Estimation Process

The demand estimation process that was followed in the Smart Corridor application is illustrated in Figure 6.4. It consists of two major phases, namely a static phase and a dynamic phase.

a. Static Phase

In the static phase, only the first time slice of the simulation period was considered (from 6:00 AM to 6:30 AM). A minimum path tree resulting from an all-or-nothing assignment from any origin to any destination of the network was built, based on the link free flow travel times. Based on this single path tree and the target link flows for the first time slice, a first run of QUEENSOD was made to produce an estimated static O/D matrix for the first time slice. This O/D matrix was then used by the ASSIGN model to produce an estimated multipath routing.

An overview of the QUEENSOD and ASSIGN modules is provided in paragraphs 6.3.2 and 6.3.3. A set of five trees was requested from the model. At the end of the static phase, this set of five trees was available together with their respective weights. These trees represent the multipath routings of the background (or unguided) traffic in the first time slice;

b. Dynamic Phase

In the dynamic phase, QUEENSOD was used to produce a dynamic O/D demand for the eight time slices of the simulation period based on:

- a time series of target link flows derived from previous TRANSYT and FREQ simulation runs;

- a time series of target link travel times also derived from previous FREQ runs;

- the set of five trees produced in the static phase of the demand estimation, which was assumed to be still valid in the following time slices. This assumption was found to be reasonable in the validation of the model's predictions, as described in section 6.4 of the report. If necessary, the model allows the user to specify a different set of routes and weights for each time slices.

6.3.2 The QUEENSOD Model

a. Introduction

QUEENSOD [21] is a model for estimating origin-destination traffic demands, based on observed link traffic flows, link travel times, and driver's route choice. The relationship between

Demand Estimation Process

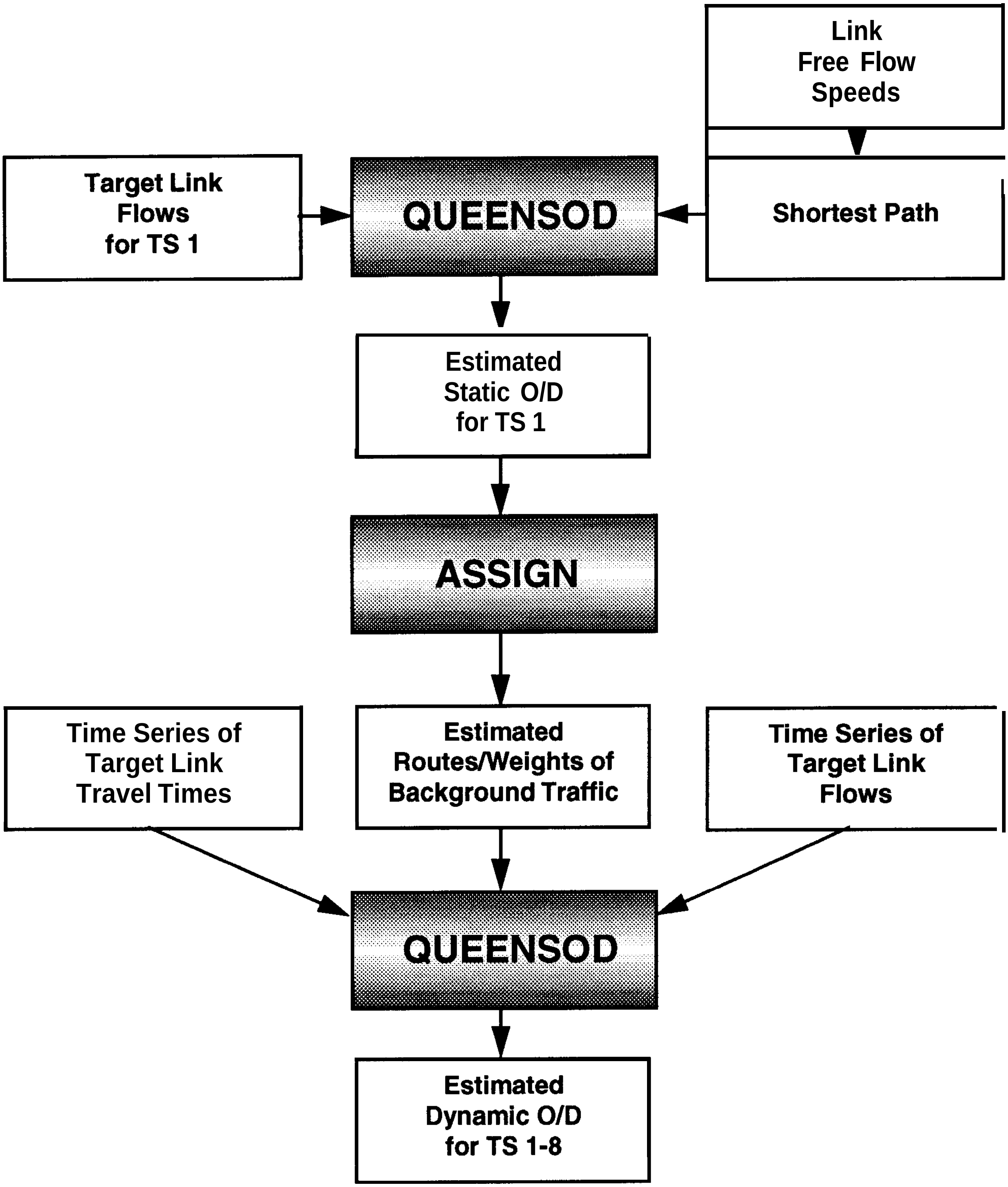


Figure 6.4

QUEENSOD and INTEGRATION was illustrated in Figure 3.2 of this report. QUEENSOD is capable of estimating both static and dynamic traffic demands. QUEENSOD has been developed at Queen's University to act as a supporting model for the INTEGRATION traffic simulation model, but QUEENSOD can also be used independently.

*b. **QUEENSOD** Model Inputs*

All the QUEENSOD input data files are compatible with either input or output INTEGRATION files. Up to six types of input data are required by QUEENSOD:

- Node descriptor (required): this file provides the X-Y coordinates of each node in the network and the node type;

- Link structure and characteristics (required): this file lists the start and end nodes of each link, the link length, the free speed, the saturation flow rate and the number of lanes;

- Actual O/D traffic demand (optional): if the true O/D traffic demands are known, the model will provide measures of how closely the estimated O/D demands resemble the true demands;

- Seed O/D traffic demand (optional): an initial seed matrix is required by QUEENSOD in order to minimize errors between the resulting link flows and observed link flows. If a seed O/D matrix is not specified by the user, the seed is computed internally by the model. When computed internally, all feasible origin-destination pair are assigned demand of 1000 vph for each time period;

- Observed link traffic flows and travel times (required): this file provides QUEENSOD with two essential data elements: a time series of observed link traffic flows and a corresponding time series of link travel times. Link traffic flows are required, as it is from these observed flows that the O/D demands that generated these flows, are estimated. The travel times are required in order for the model to determine not only where, but when demands will be observed on any link. For dynamic O/D estimation, demands are propagated along the links on the paths according to these specified link travel times;

- Paths utilized by traffic (required): in order for the model to estimate the O/D demands which have produced the observed link flows, the paths that are utilized by these demands must be known. The paths may range from a single path (as results from an all-or-nothing assignment), to some number of multiple paths with each path being utilized by some portion of the demand. These paths and associated weights may also vary over time, so that unique paths may be specified for each time period during which vehicles begin their trips.

*c. **QUEENSOD** Model Outputs*

The model provides four types of outputs for interpretation by the model user:

- On-screen: when the model is run, the user is provided with periodic on-screen test updates of the estimation status;

- Run error file: this file lists the network size constraints and provides a listing of any errors that are detected during the course of running the model;

- Estimated O/D demand file: this file provides the estimated O/D demands in a format compatible with INTEGRATION;

- Labeled output statistics: six other output files are created for analysis of the model's results:

- primary estimation results such as the root mean squared difference between observed link flows and link flows resulting from the currently estimated demand, for each iteration;

- listing of estimated and observed link flows, and the difference between them, for each link and for each time period;

- listing of all links for each estimated flows exceed capacity;

- listing of seed O/D, estimated O/D and if available, actual O/D;

- listing of all link flows discarded due to discontinuity of flow;

- analysis of observed link flows and travel times.

6.3.3 The ASSIGN Model

a. Introduction

ASSIGN [20] is a general macroscopic traffic assignment model. It assigns vehicles to certain paths based on user specified origin-destination demand rates. The relationship between ASSIGN and INTEGRATION was illustrated in Figure 3.2 of this report.

The model is capable of performing traffic assignment for both static/deterministic and static/stochastic conditions. Static equilibrium refers to the fact that the O/D demand rate in any given period is assumed to be constant. A deterministic user equilibrium assignment ensures that the drivers have perfect knowledge of the link travel times. In a stochastic user equilibrium assignment, a perception error that drivers have with regard to the link travel times is introduced.

ASSIGN has been developed at Queen's University to act as a supporting model for the INTEGRATION traffic simulation model. However, it is not necessary to have or use the INTEGRATION model to use ASSIGN to estimate traffic assignment.

b. ASSIGN Model Inputs

The ASSIGN input data files are the same as the INTEGRATION input files described in section 3.2. ASSIGN requires a listing of the nodes and their location, a listing of link information such as link length, number of lanes, free flow speeds, etc., a listing of the signal timings data, and the O/D traffic demand to be assigned.

c. ASSIGN Model Outputs

The model provides five types of outputs for interpretation by the model user:

- On-screen: if there are no errors detected, the program will display the iteration number, the total travel time,and the objective function on the screen for each iteration;

- Run error file: this file lists the network size constraints and provides a listing of any errors that are detected during the course of running the model;

- Aggregate travel time output: this file provides a link flow summary and an algorithm convergence summary. The link summary includes traffic flow, free flow travel time and the estimated travel time for each link. The algorithm summary shows for each iteration, the iteration number, the value of the objective function to be minimized and the total system travel time:

- Tree output file: ASSIGN produces a listing of the minimum path trees with their associated weighted distribution, in a format compatible with INTEGRATION and QUEENSOD input data files. The minimum path tree indicates at each node which link a vehicle should take next in order to reach the desired destination;

- Labeled output statistics: the two other output files lists other information that may be necessary in the analysis. The first file summarizes flow and travel times throughout the simulation, rather than produce average values. The second file produces statistical data.

6.3.4 Results of the Demand Estimation Process

As described in paragraph 6.3.2, the output of the demand estimation process for the Smart Corridor application is a dynamic O/D demand file that can be used directly by INTEGRATION. This output file was created after 120 iterations of QUEENSOD. The total number of vehicles to be loaded within the four hour simulation period is on the order of 190,000 vehicles.

As described in paragraph 6.3.3, QUEENSOD provides the user with some indications of the quality of the output O/D demand. The analysis of the root mean squared link flow errors is shown on Table 6.1, for the last 20 iterations of the dynamic QUEENSOD run. It can be seen that the estimated O/D demand on the last iteration was within 9.2% (= 208 / 2249.5) of the average network link traffic volumes.

Another type of analysis that was carried out is a time slice by time slice comparison of the flows estimated by QUEENSOD and the observed flows (i.e. predicted by FREQ) on the eastbound direction of the Santa Monica Freeway. Results of this analysis are shown in Figures 6.5 to 6.12. These values were tested statistically and root mean squared values of observed vs. estimated values for each time slice were calculated. The results indicate an accurate fit with no root mean squares differences below 0.97.

Time Slices (l-8)

Iteration Number	TS 1	TS 2	TS 3	TS 4	TS 5	TS 6	TS 7	TS 8	Avg.
101	231	296	360	312	266	272	240	342	290
102	208	265	334	295	252	250	211	274	261
103	198	249	319	286	245	238	201	249	248
104	192	241	311	280	240	231	194	235	241
105	187	236	305	276	236	227	189	225	235
106	184	233	301	273	233	223	186	218	231
107	181	230	298	271	231	221	183	212	228
108	179	228	295	269	229	219	180	207	226
109	177	226	293	267	227	217	178	203	223
110	175	224	291	266	225	215	177	200	222
111	173	223	289	264	224	214	175	197	220
112	172	221	287	263	223	212	174	184	218
113	171	220	285	262	222	211	173	192	217
114	169	218	284	261	220	210	172	190	216
115	168	217	282	260	219	208	171	188	214
116	167	216	281	259	218	207	170	187	213
117	166	215	280	258	217	206	169	185	212
118	166	214	278	257	216	205	169	184	211
119	165	213	277	257	215	204	168	183	210
120	164	212	276	256	214	203	168	182	209
121	163	211	275	255	214	202	167	180	208

Average network observed link traffic volume: 2249.5 vph

Number of link flows observed: 17 15

Table 6.1: Root Mean Squared Link Flow Errors

Figure 6.5

Link Flows for Time Slice 1

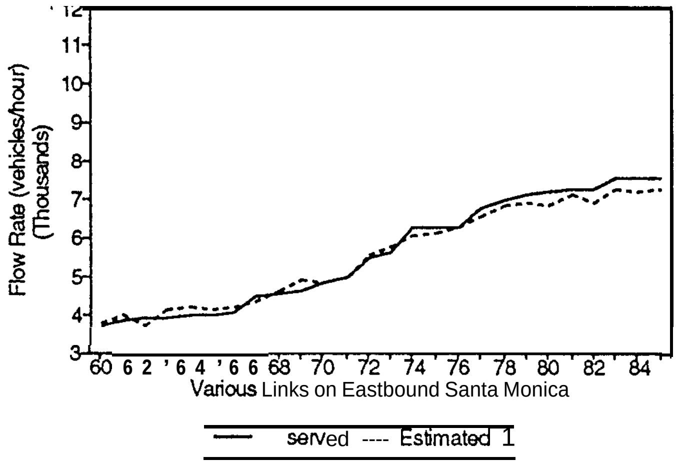


Figure 6.6

Links Flows for Time Slice 2

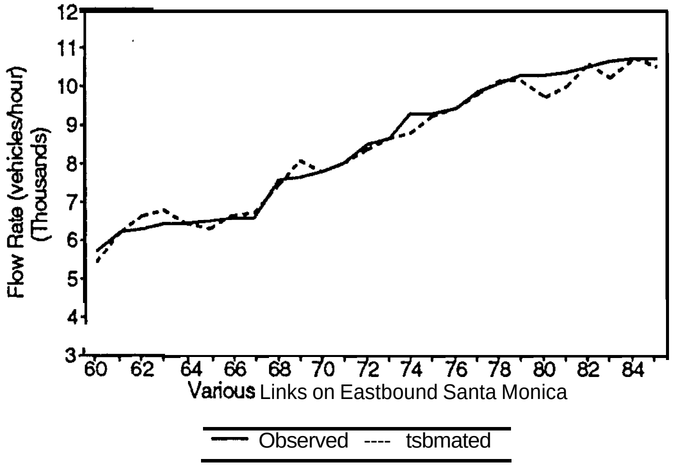


Figure 6.7

Link Flows for Time Slice 3

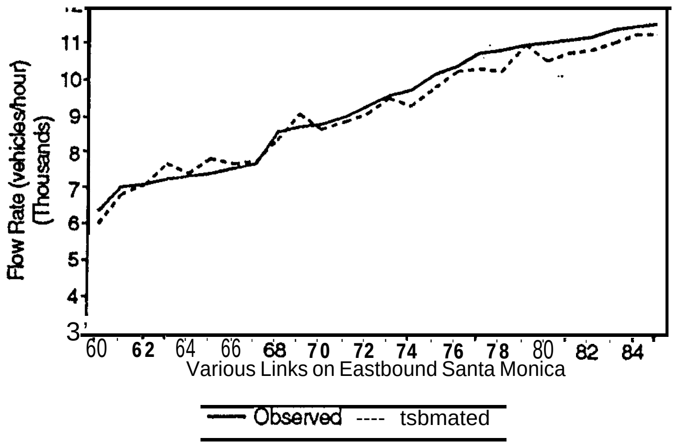


Figure 6.8

Link Flows for Time Slice 4

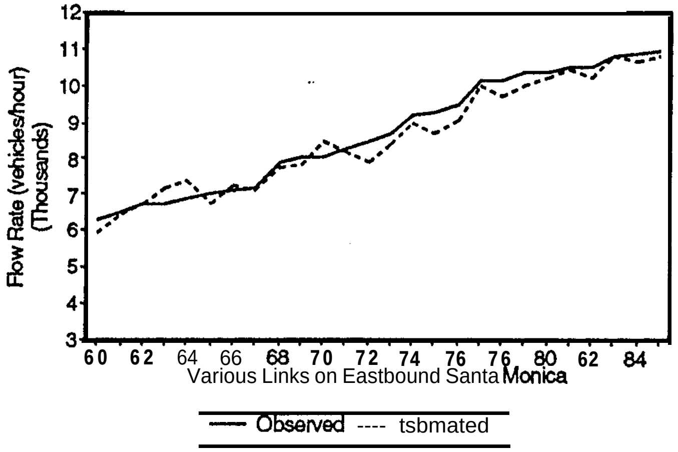


Figure 6.9

Link Flows for Time Slice 5

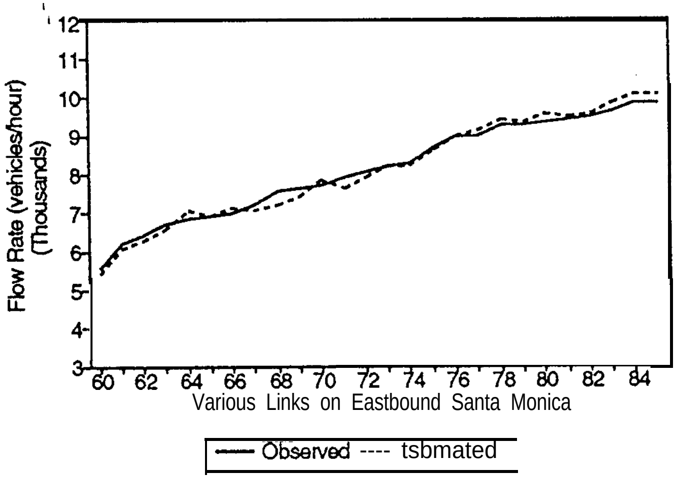


Figure 6.10

Link Flows for Time Slice 6

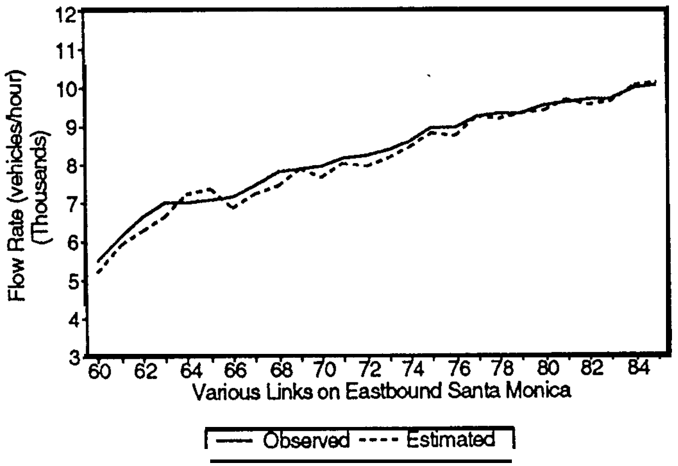


Figure 6.11

Link Flows for Time Slice 7

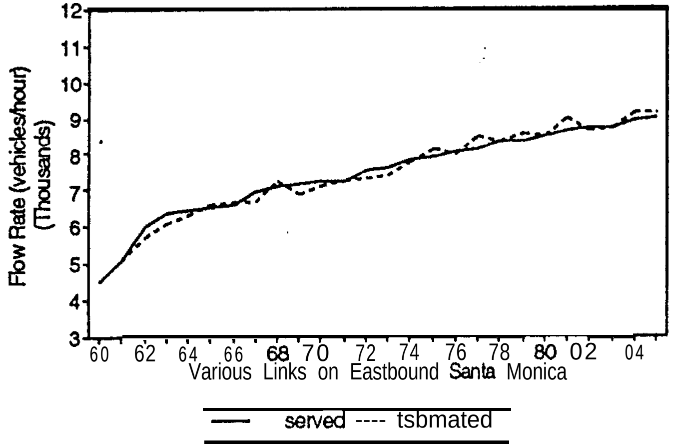
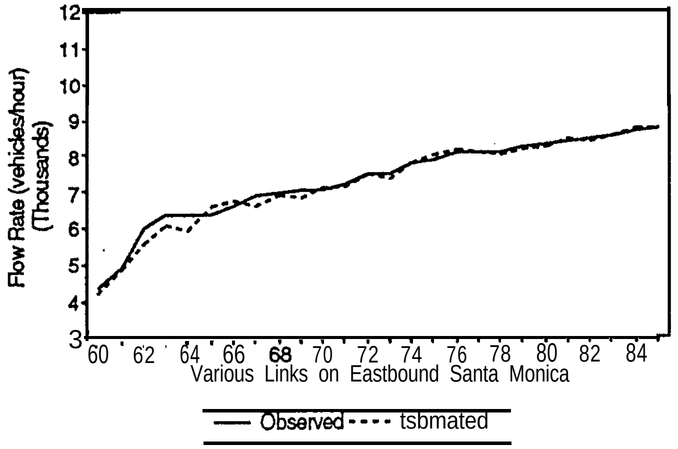


Figure 6.12

Link Flows for Time Slice 8



6.4 BASE RUN CALIBRATION

6.4.1 The Calibration Process

The calibration process that was followed in the Smart Corridor application is illustrated in Figure 6.13. Considerable simulation studies have already been done on the Smart Corridor using the FREQ, TRANSYT and CONTRAM models. This provided an extensive database with which to compare the results of the INTEGRATION application. On the freeway side, the FREQ model was successful in determining inaccuracies generated by the CONTRAM application previously carried out at ITS. For the arterial streets the performance data generated by INTEGRATION was compared to previous studies using TRANSYT.

6.4.2. Identification of Critical Parameters

Through the INTEGRATION simulation runs it became clear that the results were much more sensitive to changes in certain parameters than in others. These parameters had to be identified and optimum values had to be determined. Two types of testing were done. The first consists of using on-screen dynamic output provided by INTEGRATION and the second involves the comparison of traffic performance output tables predicted by INTEGRATION and other models. Going through this process, the most critical parameters in calibrating the INTEGRATION model for this application were identified. These parameters are listed in Table 6.2 and will be discussed later.

NETWORK	CONTROL	DEMAND	ROUTING STRATEGY
Capacity of freeway mainline links	Signal optimization	Hourly rates on main line freeway links	Vehicle types
Capacity of on and off ramps			Frequency of information update
Capacity of connector links			Distortion factor of information
Free flow speeds			

Table 6.2: Most Important Calibration Parameters

6.4.3 Calibration Using On-Screen Dynamic Output

The first level of the calibration process focused on the on-screen dynamic output. The objective was to make sure that the graphical representation of the traffic network conditions provided by INTEGRATION was realistic.

As the simulation is running, INTEGRATION provides a representation of the network that is being modelled and the vehicles travelling through it. On-screen graphics display any free-flowing vehicles as green dots, while any queued vehicles are shown as red dots. This makes it

INTEGRATION Calibration Process

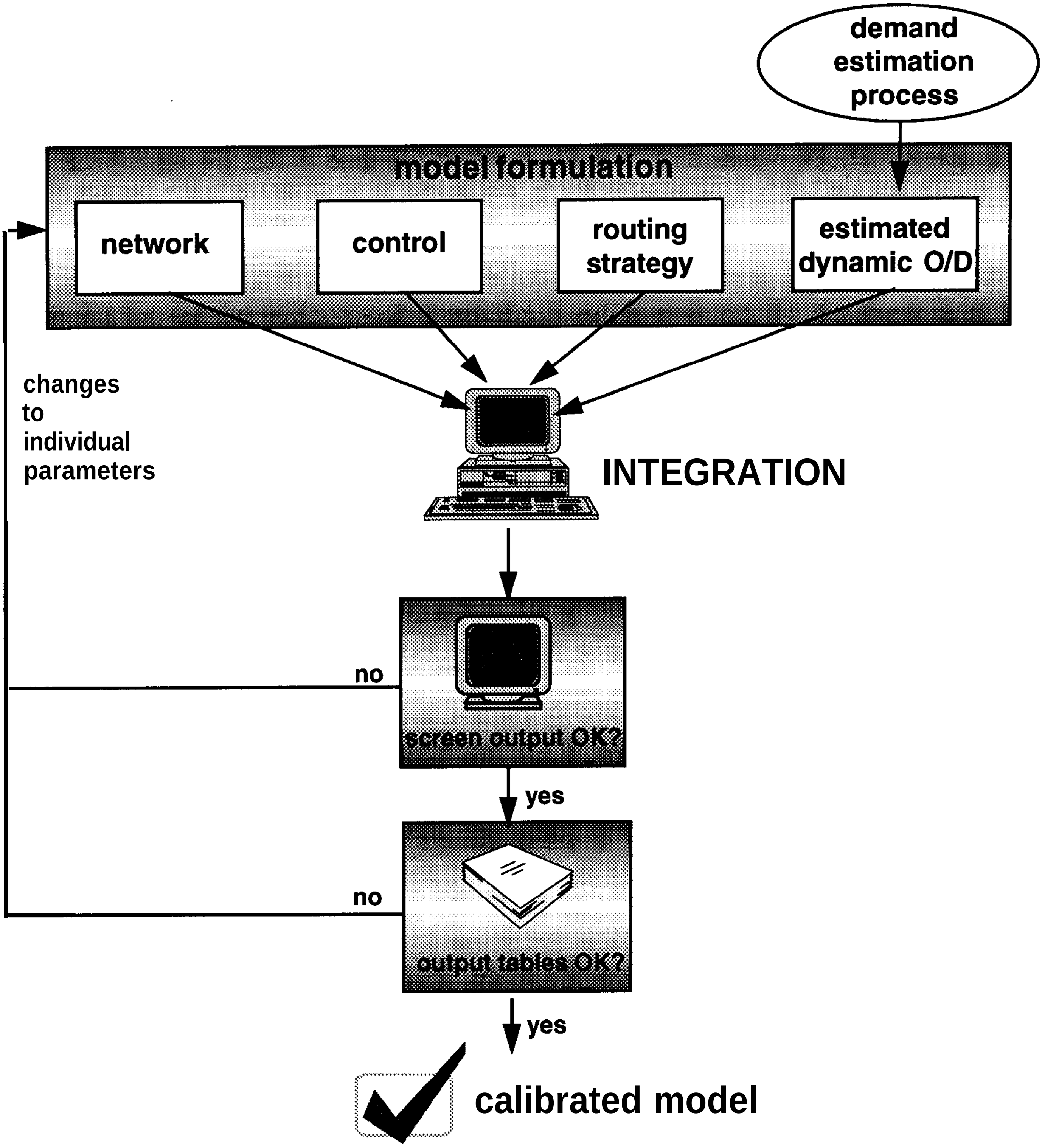


Figure 6.13

very easy to determine when and where queues are developing. Queues that are falsely predicted can be identified and rectified. Problems with the network, control and demand parameters listed in Table 6.2 were all identified using on-screen output.

a. Network

Particular attention was given to the freeway congestion pattern to verify that the bottlenecks and queue lengths were identified at the right location and at the right time, as predicted by FREQ. Some modifications were required in the network files, primarily on the freeway off-ramps characteristics. The freeway mainline capacity needed to be modified to accommodate traffic flow on the freeway. Errors in capacity on the connector links, those that connect an origin node to the rest of the system, would misrepresent total flow into the system

The off-ramps provided some difficulty as traffic often backed up all the way to the freeway. Inadequate ramp capacity was adjusted on the ramps as needed to prevent the backup.

The free flow speeds have a strong impact on traffic assignment. For example, if free flow speeds on the arterials are too high and/or free flow speeds on the freeway are too low, a lot of traffic will be routed to the freeway, and this process is likely to lead to some unrealistic traffic performance predictions both on the freeway and on the arterial side of the network.

b. Control

The problem of unexpected queues on off-ramps was often found to result from poor signal timing at the end of the off-ramps. Signal optimization provided by INTEGRATION was successful in reducing this. The signal timing initially used was from previous TRANSYT studies. This resulted in some very congested arterial intersections which were not congested in real life.

c. Demand

It was found useful to make a few changes in the O/D demand produced in the demand estimation process. The overall freeway traffic performance pattern was found to be very sensitive to minor changes in some of the O/D pair traffic demands.

6.4.4. Calibration Using Traffic Performance Output Tables

The second level of the calibration process focused on more detailed tabulations of the traffic performance predicted by the model. The idea was to compare the link travel times, flows, densities and speeds predicted by INTEGRATION against other data. Previous modelling on the Smart Corridor was done at ITS using the FREQ model for the freeways and the TRANSYT model for arterial streets. Both of these models had already been calibrated against field data. An important factor that affected the calibration was the routing strategy that the INTEGRATION model used. Determination of an optimum routing strategy allowed for a more accurate calibration.

a. Routing Strategy

As described in Chapter 3, INTEGRATION allows a whole range of traffic assignment strategies to be modelled. In the calibration stage of the Smart Corridor application, two main options were used. In the first option, vehicles were assigned based on the five fixed trees that were developed in the demand estimation process, using vehicle type 1 and data file 9 (see paragraph 3.2.9).

The second option was to test various vehicle types (1 to 5) to determine which fit the data best. Through a number of trial runs it was determined that vehicle type 2 worked best. In the INTEGRATION model, vehicle types 2 are those provided with real time information. For the base run scenario with no incidents this seems appropriate. Since only recurrent congestion is considered in the base run, the average commuter can be assumed to generally know the best path through historical information and experience of the travelled network.

Being guided vehicles, vehicle types 2 have two variables related to the guidance system, namely the F and D parameters, that must be specified (see paragraph 5.4.1.b for details). The F parameter is the frequency with which information is updated to the driver. The D parameter is the distortion factor or error introduced to this traffic information. Again various runs were made to find the most satisfying values for these parameters. It was determined that appropriate values would be one minute for F and 20 percent for D.

b. Freeway Validation

In order to facilitate the comparison between FREQ and INTEGRATION, a program was developed to transfer the INTEGRATION output file 12 (see paragraph 3.3.4) into a format compatible with the FREQ outputs. The analysis was carried out for the eastbound direction of the Santa Monica Freeway. An example of the output tables showing the travel times and densities predicted by INTEGRATION and FREQ for the freeway eastbound direction is shown in Figures 6.14. and 6.15. The values for all the links were averaged over the eight time slices of the simulation period. Other analysis included comparisons of data such as volume over capacity ratios, link speeds and link flows. The fit between the two models looked rather accurate over all these performance criteria.

c. Arterial Validation

For the arterial streets data from previous TRANSYT runs were compared to the INTEGRATION outputs. Also, some data from a field study reported in reference 3 were used in this analysis. Link travel times predicted by INTEGRATION for the two parallel arterials in the modelled network, (Adams and Washington), were compared to field data and the TRANSYT output. The results of this analysis are shown in Figures 6.16 and 6.17. The results of the INTEGRATION simulation were considered to be within the degree of accuracy needed for purposes of this study.

6.5 Conclusions

This chapter described the first step of an experiment aiming at determining the potential benefits of ATIS on the Smart Corridor. Before simulating the effects of ATIS, it was necessary to

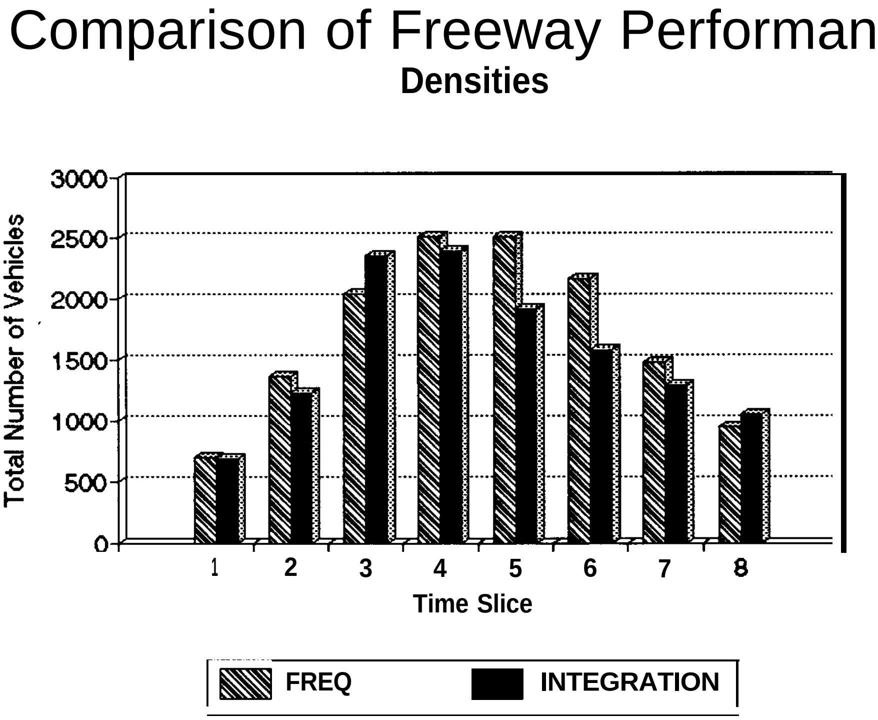


Figure 6.14

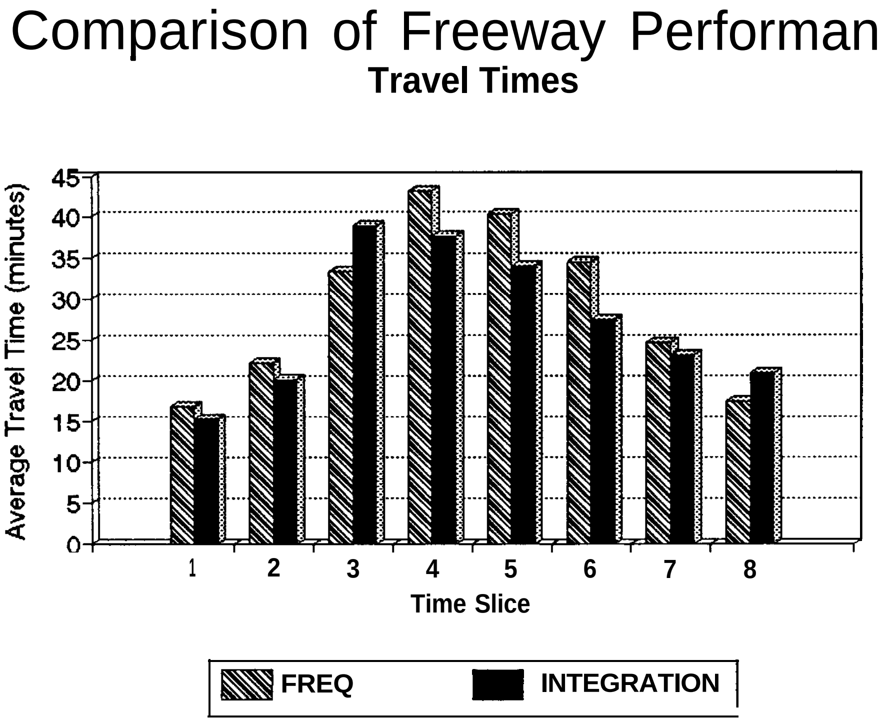


Figure 6.15

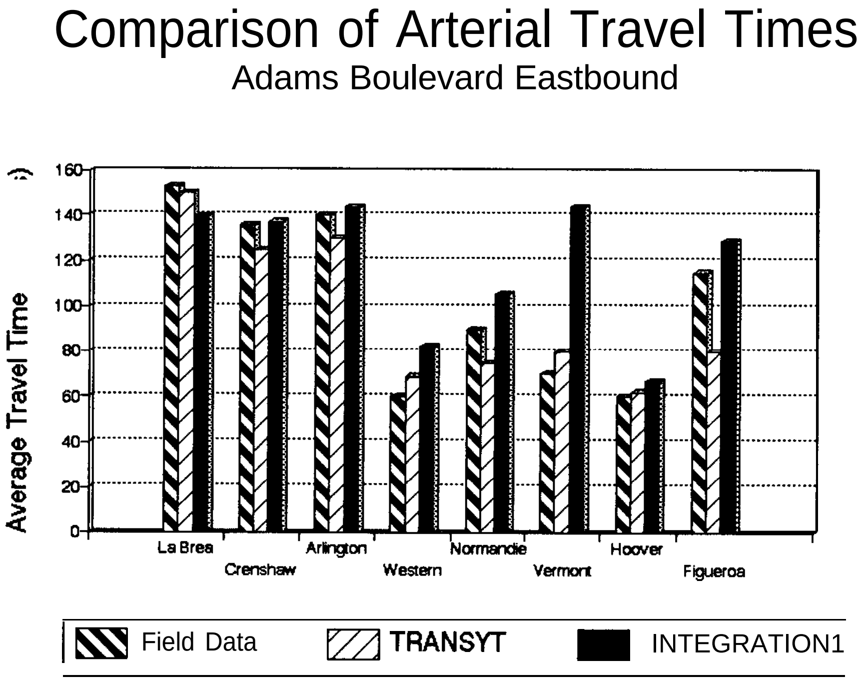


Figure 6.16

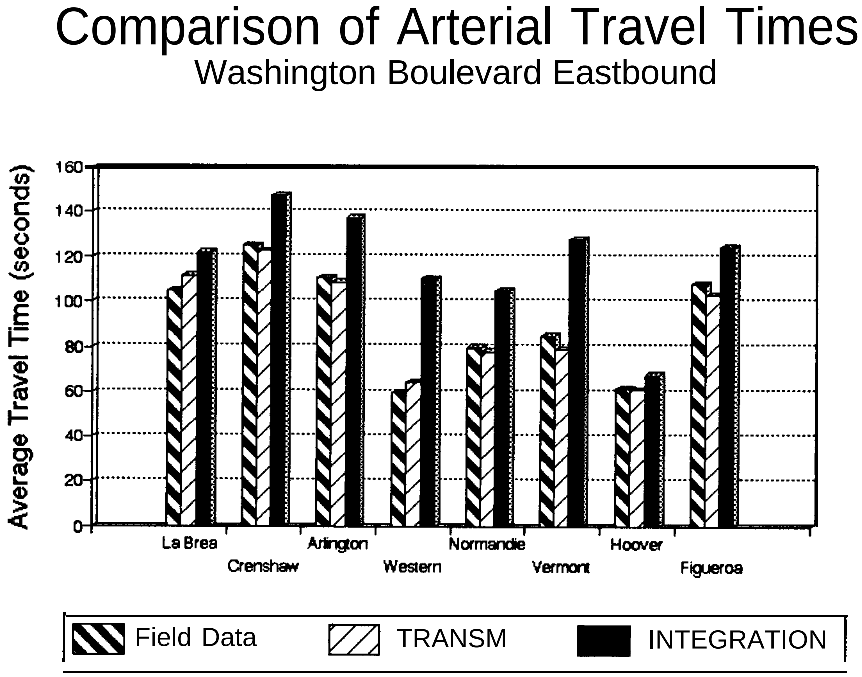


Figure 6.17

develop a reference base assignment that as closely as possible represented the Smart Corridor under typical morning peak traffic conditions. This reference base assignment (without incidents and without ATIS) is considered as the baseline to compare with the performance of the system under various percentages of ATIS equipped vehicles.

The development of the reference base assignment involved three major phases: network coding, demand estimation, and model calibration. Due to time and resource limitations and the data available, only a subsection of the Smart Corridor was coded. However, this network provided a good test-bed to assess the validity of the model to represent real-life traffic performance on a freeway/arterial environment. The demand input data that was developed for the simulations provided the opportunity to use and validate some of the model supporting modules (ASSIGN and QUEENSOD) that had been developed at Queen's University to specifically generate the inputs required by INTEGRATION. Once the necessary input data files were available, a calibration process was developed to validate the model predictions. This process consisted of three steps: identification of the model key parameters to be calibrated, calibration using the on-screen animation, and calibration using the output performance tables (speeds, flows and densities on freeway and major arterials).

The INTEGRATION traffic simulation model and the supporting modules used in this study were found to be very satisfactory in most cases. It is interesting to note that this experiment was one of the first applications of INTEGRATION to a real-life network that did not directly involve the model's developers. The ability of the INTEGRATION's approach to simulate freeway and surface street networks, and to represent traffic assignment within the same model was found to be particularly useful for this type of application.

Chapter 7: Overall Assessment and Future Study

This chapter describes the overall assessment of the completed research. First, a summary of the major findings of the study are presented; then the strengths and weaknesses of the study are described. Finally, future directions regarding further application of the modelling approach to evaluate the potential benefits of ATIS on the Smart Corridor are discussed.

7.1 SUMMARY OF MAJOR FINDINGS

Although the INTEGRATION model has recently been applied in a number of studies (Ontario, Michigan and Orlando), the application reported here was one of the first experiments which did not directly involve the model developers. Since the model is still under development, it was found useful to test and validate some of its features that were directly related to the Smart Corridor application.

After presenting the background of the project and describing some related studies, the report provided a description of the INTEGRATION modelling approach. Then, three major activities were reported: freeway modelling investigations, ATIS modelling investigations, and simulation of typical traffic conditions on the real-life Smart Corridor.

The capabilities of the selected simulation model to realistically represent oversaturated conditions on freeways was considered to be a critical model requirement. Some earlier work on the same PATH project had shown that the CONTRAM model did not accurately model high-density freeway conditions. In order to test and validate the capabilities of INTEGRATION with regard to freeway modelling, a series of experiments were performed and the predictions of INTEGRATION were compared against analytical solutions and outputs of the FREQ simulation program that was considered as the baseline. The INTEGRATION model proved to be a reliable tool for modelling freeways, particularly after the specification of the link speed-flow curves had been refined.

The second critical aspect of the model tested was the response of INTEGRATION to representing different behaviors of vehicles with and without ATIS. It was suggested that INTEGRATION includes unique tools to model ATIS; the study proved this was the case. Within the model it is possible to specify the traffic demand in terms of different driver/vehicle types that represent different level of access to real-time traffic information. Even within a driver/vehicle type class, it is possible to adjust some parameters to represent different strategies or behaviors. For example, vehicles without ATIS can be routed based on different strategies (i.e., free-flow speeds, historical knowledge of traffic conditions, or externally specified routes), and vehicles with ATIS can be provided real-time information of varying quality. Some of the key parameters involved in the representation of ATIS within INTEGRATION were identified and calibrated through a case study (the Diamond network investigation). A range of scenarios was tested that included varying the incident conditions, the quality of information provided to guided vehicles, and different levels of ATIS market penetration. While the findings of this experiment may be specific to the network-demand conditions, it appears that some of the mechanisms involved should be valid for more general conditions.

The third step of the study consisted of applying the INTEGRATION model to realistically simulate the traffic conditions on the Smart Corridor during a typical morning peak period. The resulting base conditions represent the reference conditions; the performance of the system with various percentages of ATIS equipped vehicles will be compared against this baseline. Due to time and resource limitations and the data available, only a subsection of the Smart Corridor was coded. However, this network provided a good test-bed to assess the validity of the model to represent real-life traffic performance. Also, the input data that was developed for the simulations provided the opportunity to use and validate some of the model supporting modules (ASSIGN and QUEENSOD) that had been developed at Queen's University to specifically generate the inputs required by INTEGRATION. Once the necessary input data files were available, a calibration process was developed to validate the model predictions. This process consisted of three steps: identification of the model key parameters to be calibrated, calibration using the on-screen animation, and calibration using the output performance tables (speeds, flows and densities on freeway and major arterials).

7.2 STUDY STRENGTHS AND WEAKNESSES

The main objective of this study was to test the suitability of INTEGRATION as a tool for evaluating the potential benefits of ATIS on a real-life freeway corridor. It was found necessary to assess the potential of INTEGRATION before undertaking a major effort of data collection and coding of the Smart Corridor.

INTEGRATION proved to be a good model to respond to the needs of a freeway corridor application. INTEGRATION exhibits a number of features that makes it well suited for modelling ATIS: the microscopic routing based approach; the representation of dynamic routes, flows, demands and controls; the integration of traffic simulation and traffic assignment; the ability to handle large networks combining freeways and arterials; and the linkage with support routines.

Some issues were raised when testing the modelling of ATIS. Specifically, the need for a more realistic representation of driver behavior and response to the information provided by ATIS was identified. Also, the realism of the model predictions under high levels of ATIS market penetration was found somewhat questionable under some specific network-demand conditions (see the "oscillations" that occurred with the Diamond network).

Weaknesses of the study exist and have to be recognized on the supply, demand and performance sides of the modelling process. With respect to the supply side, the real-life Smart Corridor in Los Angeles consists of a 13 mile segment of the Santa Monica freeway with five parallel arterials and approximately 15 cross streets. However, only seven miles of the Smart Corridor with two parallel arterials were coded into the model. With two parallel arterials instead of five, the opportunity for diversion is not as great as it actually is in the Smart Corridor.

On the demand side, problems exist with the structure of the zone system that was used in this application. Only external sinks and sources were used; therefore, it was not possible to consider any traffic demand coming from or going to any area inside the boundaries of the coded network.

Finally, comparisons of the simulation of base conditions on the Smart Corridor were based on a limited amount of data on observed traffic performance. The model predictions should ideally have been compared against recent field measurements of speeds and flows during a typical morning peak on the Smart Corridor. Unfortunately, such data was not available at the time the study was carried out.

7.3 FUTURE RESEARCH

A proposed project has been submitted to PATH to continue and expand the research effort with further application of the INTEGRATION model to the Smart Corridor. The application will be directed to answer questions such as:

- What are the potential benefits of ATIS equipped vehicles in terms of average travel time and travel time predictability?

- To what extend do non-equipped vehicles also benefit from the introduction of ATIS?

- Under what traffic conditions (network, demand, control) would the benefits of ATIS be greatest?

- What is the impact of ATIS market penetration?

- What are the potential benefits of ATMS strategies, primarily signal optimization on the arterials and ramp metering and CMS strategies? What are the potential interactions between ATMS and ATIS strategies?

It is anticipated that these tasks will first be performed using the current input data files. However, it is intended to incorporate a number of refinements. First, the network would be expanded to cover the entire Smart Corridor. Then, the simulation period would be extended to an entire day including AM and PM peaks, and updated traffic performance information would be collected to refine the input data files and to calibrate the model predictions.

Further investigations could also be performed. For instance, a number of open issues in ATIS system architecture could be identified and investigated, such as update information frequency, beacon density, user optimization vs. system optimization routing strategies, and central vs. distributed intelligence approaches. Another area of investigation would be the representation of various types of driver's behavior in response to route guidance systems.

Future applications of INTEGRATION should further establish the model as a very useful tool for ATIS and ATMS modelling, and provide valuable information on design and effectiveness of new and proposed systems.

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