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This paper is part of an effort to simulate various IVHS strategies on the Santa Monica freeway corridor (I-10) in **Los** Angeles. This corridor is also known as the "Smart Corridor" because of the project of the same name that is currently underway on the corridor. While much of the data used for this report were obtained from the agencies involved in the Smart Corridor project, it should be made clear that this research was conducted at the University **of** California at Berkeley and is not a part of the Smart Corridor project itself. The results arrived at in this report do not necessarily reflect the views of any of the agencies involved in the Smart Corridor project.

EXECUTIVE SUMMARY

Background

A preliminary evaluation of potential benefits of ATIS on the Santa Monica freeway corridor in **Los** Angeles was conducted by an Institute of Transportation Studies research team in 1988 and 1989 using the **FREQ** and TRANSM 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 Santa Monica freeway corridor. Some difficulties were encountered in the modelling of the freeway portion of the corridor.

Work with the INTEGRATION model started in 1992. Phase 1 of the study included testing of the model on a series of hypothetical networks. Special attention was given to evaluate INTEGRATION's response to the need for realistic freeway simulation modelling and accurate representation of the differences between vehicles with and without ATIS. Phase **1** also involved the development of the reference base assignment for the Santa Monica freeway corridor investigations. Before simulating the effects of ATIS and ATMS, it was necessary to develop a baseline **(i.e.,** without incidents and without IVHS) to compare with the performance of the system under various ATIS and ATMS strategies.

Project Scope and Objectives

The general objective of the project is to investigate and quantify the likely benefits of implementing various ATMS and ATIS control strategies on the real-life Santa Monica freeway corridor in **Los** Angeles.

The different strategies to be tested in Phase 2 include freeway ramp metering, real-time traffic signal optimization, route guidance systems, and combinations of these strategies. Investigations of different strategies are performed for the same network conditions (portion of the Santa Monica freeway corridor previously coded in Phase 1) and under the same demand level (typical morning peak period). Effects of incidents are to be analyzed.

Primary focus at this stage of the study was more on developing and testing the methodologies for modelling various IVHS strategies than on the quantitative simulation results.

Findings

The selected traffic simulation model, INTEGRATION, proved to be a valuable tool to represent freeway ramp metering, real-time traffic signal control, route guidance systems, and their interactions, in a freeway corridor environment under both no-incident and incident conditions. However, some issues were identified when testing the modelling of these control strategies. It was shown that in some cases, the model would not represent the optimal control strategy, but only a step towards optimization.

In regard to ramp metering, the need for the representation of real-time control was identified. The version of the program utilized in this study could only represent fixed-time metering plans which had to be developed by running another simulation model (FREQ in this case). It would probably be more effective to model dynamic ramp control directly within INTEGRATION. The fixed-time metering plan, developed for no-incident conditions, was obviously not suitable after the introduction of incidents. Concerning the modelling of real-time signal optimization, the model had the ability to represent dynamic optimization of cycle lengths and splits at isolated intersections. This strategy was found to be helpful in most cases. However, signal coordination optimization was not available within the version of the model used in this study. In terms of modelling route guidance systems, the need for a more realistic representation of driver behavior and response to the information provided to the equipped vehicles was identified as a critical aspect to be refined in the model.

Because of the assumptions incorporated within the modelling approach and the very specific features of the network/demand conditions, it was recognized that the simulation results should be viewed with caution. The results are best considered in a somewhat qualitative manner with the findings being that the expected benefits of ATIS and ATMS are higher under incident conditions. The control strategies with dynamic traffic- responsive features are always more helpful, especially under non-recurrent congestion. In presence of severe freeway incidents, the selection of an appropriate control strategy could improve the system performance to a level that is similar to what it was before the incident occurred.

Future Work

Future research is needed to develop and incorporate an optimum metering rate algorithm and an optimum signal timing algorithm within the INTEGRATION model. Further testing and refinements of the modelling of dynamic route guidance is also needed.

For the specific application to the Santa Monica freeway corridor, it would be desirable to investigate other ATIS/ATMS control strategies, such as on-freeway **HOV** lanes, CMS or HAR strategies. Improvements in the simulation of the corridor could also be achieved **by** collecting recent traffic performance data and refining the O/D demand estimation.

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1. INTRODUCTION

1.1 Project Scope and Objectives

Development of Advanced Traffic Management Strategies (ATMS) and Advanced Traveler Information Systems (ATIS) are likely to offer substantial opportunities for improving traffic efficiency and reducing congestion in urban areas. ATMS include 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.

There are a number of unanswered issues which still have to be addressed before any large scale deployment of these new technologies 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. Traffic simulation and assignment models are particularly valuable as an aid to system design for identifying key operation and performance issues, for testing under a range of scenarios (system, network, traffic), and for refining strategies before implementation.

A multi-year research study is underway at the University of California at Berkeley as part of the California PATH Program to investigate and quantify the likely benefits of implementing various ATMS and ATIS control strategies on the Santa Monica freeway corridor in Los Angeles. The different strategies to be tested include freeway ramp metering, real-time traffic signal optimization, HOV priority treatment, route guidance systems, and combinations of these strategies. Strategies are assessed in terms of travel time savings, trip distances, travel time predictability and average speeds. Particular attention was given to the balance of traffic between the freeway and the surface streets under different IVHS control strategies. The congestion effects of ATMS and 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 studied.

In order to address these questions, a modelling approach was selected. Through the use of simulation, it is possible to investigate many potential scenarios under many different circumstances, and many statistics on the behavior of the system can be obtained. The INTEGRATION traffic model, developed at Queen's University in Kingston, Canada, is being used for this application, as several characteristics of this model make it a powerful and rather unique tool for network analysis in the IVHS context.

1.2 Study Approach/Background

This study is a continuation of the original work by May et al.[1]. 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 IVHS on the Santa Monica freeway corridor. Thus, a study was begun to investigate the candidate models potentially suited for the purposes of this project [2]. An initial application of the CONTRAM model was carried out and reported in 1991 [3]. Problems with the CONTRAM program were encountered, primarily in regard to modelling oversaturated conditions on the freeway.

A new phase of the project started in the fall of 1991 with the application the INTEGRATION traffic simulation model. INTEGRATION was developed specifically to deal with representation of networks combining freeways and arterials. Prior to investigations on the entire Santa Monica freeway corridor, the INTEGRATION model was applied to a number of different traffic demand-supply networks in order to test the validity of the model and to evaluate various model features. A research report [4]was prepared to summarize the various experiments carried out to validate the model capabilities with regard to freeway modelling and ATIS modelling. The same report described the initial application of the model to a portion of the Santa Monica freeway corridor, leading to the development of a reference base run. This reference base assignment (without incidents and without ATMS or ATIS) was considered as the baseline to compare with the performance of the system under various ATMS and **ATIS** control strategies. In addition to the PATH report [redacted] further discussion of investigations performed in Phase 1 of the project can be found in two papers (ref.[5] and [6]).

The present report describes a new phase of the study (referred as Phase **2)** consisting of initial experiments of ATIS and ATMS modelling on a portion of the Santa Monica freeway corridor that was coded and calibrated in Phase 1 of the project. Investigations are performed for the morning peak period under both incident-free and incident traffic conditions. Strategies tested at this stage include freeway ramp metering, traffic signal optimization, route guidance systems, and their interactions.

Further research will include refinements on the supply, demand, control and performance sides of the simulation process. The entire Santa Monica freeway corridor is intended to be coded next, for a full day of operation. An extensive set of traffic performance data will have to be collected to compare the simulation results with real-life observations. *Also*, the modelling of some control policies could be improved, and some additional control strategies could be tested (such as implementation of HOV lanes).

1.3 Organization of the Report

Chapter **2** of this report outlines the history and background of the study, focusing on the development of a reference base run representing typical traffic conditions on the Santa Monica freeway corridor during the morning peak period. Chapter **3** describes the methodologies developed to simulate different control strategies (freeway ramp metering, signal optimization, route guidance) within the INTEGRATION model. Chapters **4** and ***5*** summarize the results obtained when these strategies were modelled with INTEGRATION under no-incident conditions (Chapter **4)** and incident conditions (Chapter 5). Finally, Chapter 6 provides an overall assessment of the study and discusses the potential for future research.

2. BACKGROUND: DEVELOPMENT AND VALIDATION OF BASE RUN

2.1 Introduction

With the goal of determining the potential benefits of ATMS and ATIS in a real-life freeway/arterial network, an experiment was designed to simulate the Santa Monica freeway corridor with the INTEGRATION model. It was necessary to first develop a reference base assignment that as closely as possible represents the Santa Monica freeway corridor under typical morning peak traffic conditions (6:00 AM to 10:00 AM). This reference base assignment (without incidents and without ATMS or ATIS) was considered as the baseline to compare with the performance of the system under various ATMS and ATIS control strategies.

The development of the reference base assignment is described in detail in reference [4] and is briefly summarized in the rest of this chapter. Three major phases were involved, namely, network coding, demand estimation, and model calibration. Due to time and resource limitations and the data available, only a portion of the Santa Monica freeway corridor was coded.

2.2 Network and Control Configuration

The study area is illustrated in Figure 2.1 and involves about nine miles of the Santa Monica Freeway (I-10) with associated ramps, and two parallel arterials: Washington Boulevard and Adams Boulevard (both eastbound and westbound). Also included in the network is a segment of the Harbor Freeway and eleven (11) streets connecting Adams, Washington and the Santa Monica Freeway (both northbound and southbound). La Cienega Boulevard (West) and the Harbor Freeway (East) form the boundaries of the network. The number of links in the coded network is 308 (60 uncontrolled freeway links, 60 ramp links and 188 arterial and major street links).

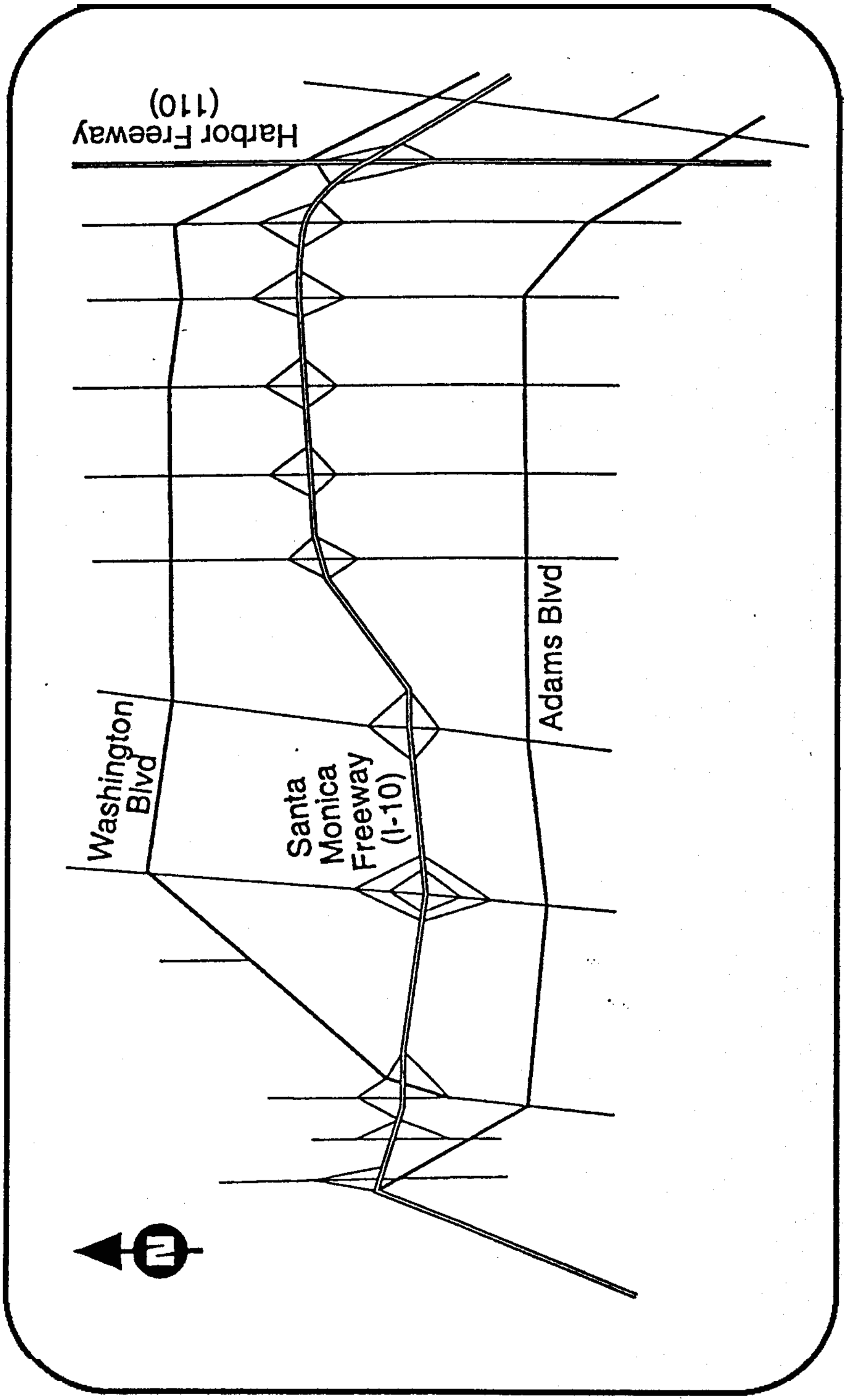
The signal timing data were taken from TRANSYT files based on 1988 data provided by the City of Los Angeles. Traffic signals were coded with fixed-time signal timings.

2.3 Demand Estimation

The simulation period (6:00 AM to 10:00 AM) was divided into eight 30 minute time slices. The demand estimation involved the use of a synthetic origin/destination matrix estimation technique called QUEENSOD to derive the O/D tables. QUEENSOD [7] is a model for estimating origin-destination traffic demands, based on observed link traffic flows, link travel times, and driver's route choice. QUEENSOD was developed at Queen's University to act as a supporting module for the INTEGRATION traffic simulation model. Statistical analysis presented in reference [4] suggested that the demand rates predicted by QUEENSOD were reasonably close to the target counts, as observed in 1988.

It should be noted that the demand is assumed to be independent of the control policies that will be simulated and analyzed in Chapters 4 and 5 of this report.

Figure 2.1
Network Layout



2.4 Calibration of Base Conditions

Once the necessary input data files were available, a calibration process was initiated to validate the model predictions. **A** number of model parameters were found to be of critical importance in the validation process; these parameters included the capacities of freeway mainline and ramp links, the free flow speeds, the demand rates for freeway mainline O/D pairs, and the routing strategy to be used by the vehicles.

These parameters were calibrated first using the on-screen animation provided by the model, and then using various output performance statistics. **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 very easy to determine when and where queues are developing.

A more detailed analysis of the traffic performance predicted by the model was also performed. The objective was to compare the dynamic link travel times, flows, densities and speeds predicted by **INTEGRATION** against other data. Previous modelling on the Santa Monica freeway corridor had been performed within the same project using the FREQ freeway simulation model and the TRANSYT model for arterial streets [1]. Both of these models had already been calibrated against field data, and **INTEGRATION** proved to be able to predict comparable traffic performance [4].

3. MODELLING DEVELOPMENTS

3.1 Introduction

Following the development of the reference base run, this chapter describes how the INTEGRATION model was used to represent the effects of freeway ramp metering, traffic-responsive signal optimization, and route guidance systems.

All the model features used in the Santa Monica freeway corridor application of INTEGRATION are standard features available in Version **1.4** d of the model released in May 1992. Further details about the modelling approach, the input data requirements and the model outputs can be found in the Model User's Guide [8].

3.2 Modelling Ramp Metering

Ramp metering control was implemented within INTEGRATION using a simple traffic signal, whose cycle length and green phase duration was selected to produce the desired 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.

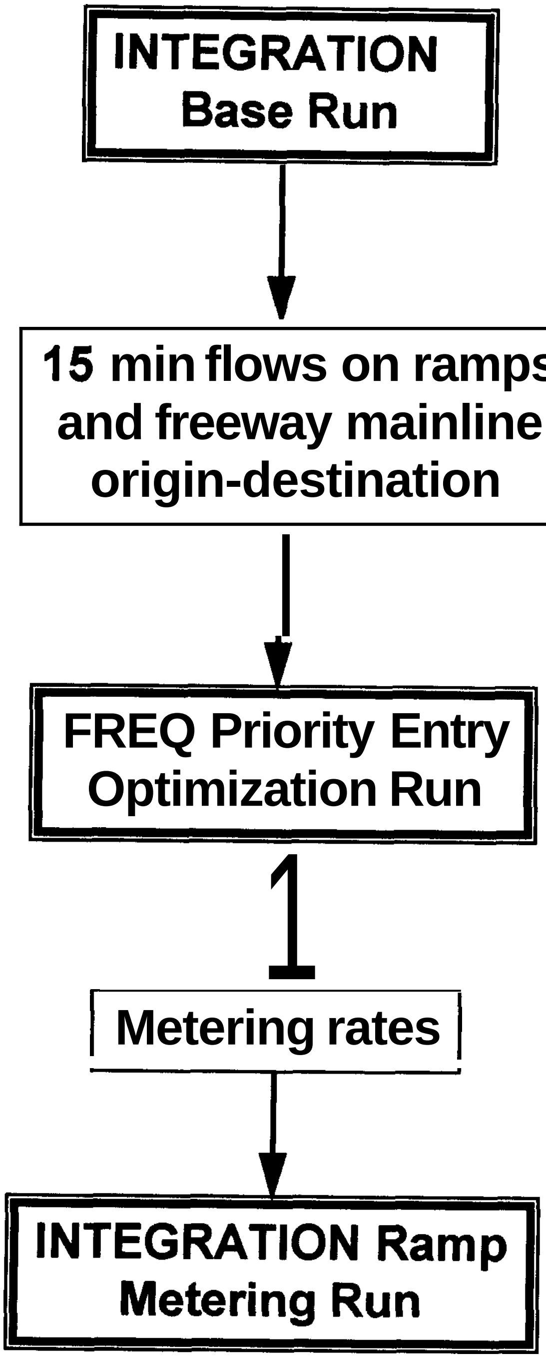
The version of INTEGRATION used in this study (Version **1.4** d) does not allow for internal real-time ramp metering control. For the Santa Monica freeway corridor experiment, time-of-day fixed-time ramp metering plans were determined by first running the FREQ freeway simulation and optimization model. Figure **3.1** illustrates the process that was followed and the interactions between successive INTEGRATION and FREQ runs.

It should be noted that the objective of the simulation study was not to try to replicate the ramp metering plan currently in use on the Santa Monica freeway corridor. Instead, the intend was more oriented towards developing an optimized ramp metering strategy for the specific network/demand/control conditions considered in this application.

FREQ [9] is a macroscopic and deterministic freeway simulation model that was developed at the University of California at Berkeley. It has been in existence since the 1960's and has been extensively used in freeway traffic studies. FREQ can calculate an optimal on-ramp control strategy based on the maximization of an objective function such as the total number of vehicles on the freeway, given a set of constraints.

FREQ was used in the Santa Monica freeway corridor modelling study to develop the optimal ramp metering plan for the morning peak period on the eastbound direction of the Santa Monica freeway. Inputs to FREQ include dynamic demand flow rates at the ramps and mainline origin/destination. These flow rates were determined by an initial run of INTEGRATION (similar to the reference base run described in Chapter **2)** which produced link volumes every 15 minutes. Based on these demand rates, FREQ was used to derive an optimal metering plan. The desired metering rates determined by FREQ were converted into signal timing data to be used by INTEGRATION on the metered freeway on-ramps. A uniform green time duration of two

Figure 3.1
Ramp Metering Analysis Flowchart



seconds (ie. one vehicle discharged at a time) was used for all the metered ramps; the red time duration was then selected to produce the desired ramp metering rate.

By going through this process, it is clear that the ramp metering plan implemented within Figure INTEGRATION can not be regarded as the true optimum metering plan for several reasons:

1. Ramp metering control was activated for the freeway eastbound direction only, whereas an optimal metering strategy on the Santa Monica freeway corridor would be expected to be implemented also on the westbound direction (flows are heavy in both directions during the morning peak period);

2. Ramp metering rates were allowed to vary only every 15 minutes, whereas an optimal strategy is likely to require more frequent changes in the metering rates;

3. Ramp metering rates were originally optimized by FREQ for an initial set of flows derived from the INTEGRATION base run (with no ramp metering). However, the introduction of ramp metering control results in changes of driver's routing decisions. Therefore, the final ramp flows in the INTEGRATION simulation were slightly different from the flows used in the FREQ optimization run.

For these reasons, the ramp metering process that was followed in this application does not demonstrate potential benefits of fully optimized ramp metering strategies. A possible enhancement would be to incorporate within INTEGRATION a more direct modelling of local traffic-responsive ramp metering control strategies. This could be done by simulating a typical local actuated metering strategy which limits the entrance ramp volume to a desired value by correlation with the occupancy (or density) level on the adjacent freeway mainline traffic. As an example, Table 3.1 provides a possible relationship between freeway occupancy levels and ramp metering rates (source: ref.[10]).

Occupancy (%)	Metering rate (veh/min)
< 11	12
11 to 16	10
17 to 22	8
23 to 28	6
29 to 34	4
> 34	3

Table 3.1: Example of Local Traffic-Responsive Metering Rates

3.3 Modelling Real-Time Traffic Signal Control

In the base run, signal timing data (split, cycle length and offset) for each signalized intersection were obtained from previous studies in the form of TRANSYT input data files based on earlier information provided by the City of Los Angeles (circa 1988). No traffic-responsive signal control was considered in this base run. Instead, time-of-day fixed-time control was modelled by providing several different signal timing plans, each plan being in effect for 30 minutes.

INTEGRATION has the capability to represent automatic internal signal re-timing. When the automatic internal signal re-timing is utilized, only the offsets and the lost times specified in the original signal timing plan file are kept constant. The other timing plan parameters (cycle length and phase splits) are optimized every "signalopt" seconds based on a running exponential average of the upstream traffic inflow rates for each controlled link. The value of "signalopt" must be in multiples of 60 seconds and is specified by the user. The procedure utilized for the signal timing plan optimization allocates green time based on the approach's volume/saturation flow ratios, according to the procedures specified in the Canadian Capacity Guide. The analyst can specify for each signal the minimum/maximum cycle length constraints.

It should be noted that, while signal coordination is always modelled within INTEGRATION, no signal coordination optimization is considered in the current version of the model. Instead, signal coordination settings are held constant, while each signal is being optimized as being isolated. A research study is currently underway at Queen's University [11] to incorporate within INTEGRATION an approach to real-time control which is very similar to SCOOT (incremental on-line optimization of cycle length, phase splits and offsets). It is anticipated that this simulation module can shortly be incorporated into the IBM PC version of INTEGRATION.

The strategy tested on the Santa Monica freeway corridor experiment consisted of optimizing cycle lengths and splits for each controlled intersection every **3** minutes with a minimum cycle length of 30 seconds and a maximum of 120 seconds. While improvements in system performance are expected, it would not demonstrate the maximum benefits of signal optimization.

3.4 Modelling Route Guidance Systems

In an earlier study within the same project, capabilities of INTEGRATION with regard to modelling various types of route guidance systems were tested on a simple hypothetical network [6]. This study concluded that INTEGRATION proved to be a reliable tool for simulating RGS because the model has the ability to represent different routing behaviors based on different access privileges to real-time information for each vehicle.

The route guidance function within INTEGRATION is closely tied into the traffic assignment function, as the assignment is based on a traffic routing procedure. The impact of route guidance systems can be estimated by considering different driver/vehicle types.

The first type of vehicle is typically considered to represent drivers without access to real-time traffic information. It can be assigned routings based on externally specified path trees. In this mode, it is possible 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,

The second type of vehicle (driver) 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 form of dynamic in-vehicle route guidance systems. The trip time information provided to RGS equipped vehicles is based on current link by link travel times. There is no provision for predictions of future travel times in the current version of INTEGRATION. In this respect, modelled RGS strategies might in some cases be inferior to actual human behavior.

Changeable message signs (CMS) and highway advisory radio (HAR) can be modelled by providing traffic information only at selected locations.

The quality of trip time information provided to driver/vehicle type 2 can be controlled by two parameters: the update information frequency and the distortion factor. 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 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. 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 fact that even vehicles equipped with in-vehicle route guidance systems 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 imperfect way to reflect the fact that all the guided vehicles do not always comply with the routing provided by the on-board guidance system.

In the Santa Monica freeway corridor experiment, the guidance strategy was typically implemented under the assumption that 25% of the vehicles were equipped. The equipped vehicles were modelled as vehicle types 2 with routing instructions updated every 10 seconds at every node and no distortion in the travel time information. Following the strategy that was found to give the most satisfying results in the development of the base run, the non-equipped vehicles were also modelled as vehicle types **2.** This seemed appropriate since under recurrent congestion conditions, the average commuter can be assumed to generally know the best path through historical information and experience of the travelled network. However, these vehicles were provided with less accurate information than guided vehicles, as the link database was updated only every minute and a distortion factor of 20% was introduced (both under recurring and non-recurring conditions).

Effects of different RGS market penetration were also analyzed on the Santa Monica freeway corridor by varying the rate of equipped vehicles from 0 to 100%.

3.5 Modelling Combination of Control Strategies

The flexibility of INTEGRATION derives from the fact that the different control strategies can be simulated independently or simultaneously. This provides the opportunity to compare system performance under a range of possible control strategies. In particular, the proportion of **RGS** equipped vehicles can be specified for each run. The equipped vehicles are forced to interact with the non-equipped vehicles as well as with the implemented traffic management strategies.

4. INVESTIGATIONS UNDER RECURRING CONGESTION CONDITIONS

This chapter describes the initial results obtained when simulating various ATMS and ATIS strategies on the Santa Monica freeway corridor, under incident-free traffic conditions. Effect of incidents will be described in Chapter 5 of this report.

4.1 Design of Experiment

An experiment was designed to test the potential effects of ATMS and ATIS control strategies on the coded portion of the Santa Monica freeway corridor during the morning peak period. A total of six control strategies were modelled with the same network characteristics and under the same demand level. The different control strategies or scenarios were the following:

1. Base conditions (no ATMS, no ATIS);
2. Ramp metering control;
3. Real-time traffic signal optimization;
4. Combined ramp metering and signal optimization;
5. Route guidance;
6. Combined ramp meteringlsignal optimization/route guidance.

4.2 Main Assumptions

The methodologies for modelling each control strategy were described in Chapter 3 of this report. The main modelling assumptions and limitations are summarized in this section. Ramp metering control was modelled for the freeway eastbound direction only; metering rates were not optimized on-line, but were derived from an initial FREQ run. The modelled traffic signal optimization strategy does not include optimization of the offsets or the number and sequence of phases; therefore, no signal coordination optimization is represented.

Because of these assumptions, the results reported in the remainder of this chapter should be viewed with some caution and considered only as initial findings which will have to be confirmed. In particular, it was recognized that the modelled ramp metering and traffic signal optimization strategies did not represent true optimal strategies, but only a step towards optimization. Primary emphasis in this study was more on testing the methodologies for modelling different strategies than on the quantitative results. However, some interesting findings came out of this study and are presented in the rest of this chapter and in Chapter 5.

A tabular summary of the results is given in Table 4.1 and graphical analyses are also provided in Figures 4.1, 4.2 and 4.3. The results are summarized by link type (freeway, ramp, arterial and overall) as it was found to be helpful in analyzing the results.

4.3 Scenario 1: Base

The base scenario refers to the initial run with no ATMS or ATIS. This is the reference base run described in Chapter 2 of this report, against which all other scenarios will be compared. The INTEGRATION output for this incident-free base case run is summarized in the first column of Table 4.1. The overall average speed is 48.5 km/h (or 30 mph). **A** total of 189,973 vehicles were loaded onto the network over the four-hour simulation period. The average overall trip time was 6.7 minutes for an average trip length of **5.4** km (or 3.4 miles). Note that the freeway average speed of 58.8 km/h (37 mph) indicates a high level of congestion.

4.4 Scenario 2: Ramp Metering

In Scenario **2,** time-of-day fixed-time ramp metering plans for eastbound 1-10 were obtained by first running the FREQ freeway simulation and optimization model, as described in Section 3.2 of this report. **As** shown in Table 4.1, the introduction of ramp metering control on the freeway eastbound direction resulted in a slight increase (+1.9%) in the overall network average speed (from 48.5 km/h to 49.5 km/h). It also appears that the freeway travel times were reduced (by 6.1%) while the trip times on the ramps and arterials were increased (by 1.9% and 3.9% respectively).

4.5 Scenario 3: Signal Optimization

In Scenario 3, cycle lengths and splits of each controlled intersection were optimized every **3** minutes with a minimum cycle length of 30 seconds and a maximum cycle length of 120 seconds. **As** shown in Table 4.1, the implementation of this strategy resulted in a slight increase of the overall system speed from 48.5 to 49.1 km/h. **As** expected, the arterials particularly benefitted from signal optimization as the arterial trip time was reduced by 2% while the distance travelled increased by 3.9%.

4.6 Scenario 4: Combined Ramp Metering and Signal Optimization

With combined ramp metering and signal optimization (Scenario 4), the arterials experienced a significant increase in travel distance (+11.9%) showing the traffic was balanced between the freeway/ramp system and the surface streets. However, the arterials also experienced a serious increase in trip time (+11.3%), suggesting that the additional traffic could not be accommodated without causing increased delays.

4.7 Scenario 5: Route Guidance Systems

The effect of RGS was analyzed in Scenario 5 for a 25% level of equipped vehicles. The effect of varying the level of market penetration will be discussed in Section 4.9. Table 4.1 shows that a 3.6% increase in the overall average speed was achieved in Scenario **5**. Freeways, ramps and arterials simultaneously benefitted from the introduction of guidance systems, which resulted in a slight change of distribution of traffic between the freeway and the surface streets.

4.8 Scenario 6: Combined Ramp Metering, Signal Optimization and RGS

The combination of ramp metering, signal optimization and RGS (Scenario **6)** produced the best overall system performance, with an increase in the average network speed of 6.3%, and an increase in the average freeway speed of 11.6%.

These results can be evaluated from two perspectives, namely, the effect of ATIS on ATMS, and the effect of ATMS on **ATIS.** The introduction of RGS in addition to ATMS did not result in significant changes in routing behavior, as the travel distances in Scenarios 4 and 6 appear to be very similar. However, in terms of trip times, the assignment with RGS is better, as additional trip time savings are experienced on freeways and ramps, while the arterial trip time is also slightly reduced. The ATMS effect on RGS appeared to be significant in terms of routing patterns, as a significant amount of traffic was shown to balance from the freeway system to the arterials. This traffic balance resulted in significant trip time savings on freeway and ramps.

4.9 Effect of RGS Market Penetration

4.9.1 System Benefits

Different percentages of driver population with route guidance systems (0%, **5%,** 10%, 15%, 25%, 50%, **75%** and 100%) were tested to analyze the effects of varying equipment rate. Systems benefits were evaluated in terms of overall system trip time (veh.hrs). Note that, for each run, the ramp metering control and signal optimization were also activated.

Figure 4.4 shows the relationship between total trip time and the percentage of RGS-equipped vehicles. The shape of the function indicates that when only a small percentage of drivers has access to real-time guidance, the total decrease in overall travel time is significant. **As** more users gain access to information (above 15% equipment rate), travel time decreases at slower rates. This pattern agrees with the intuitive expectation that marginal benefits from providing information decrease when the rate of RGS market penetration increases.

The minimum trip time value (system optimum) occurs when all the vehicles are assumed to be equipped with RGS, and a total trip time reduction of **6.2%** is shown to occur in this case.

4.9.2 User Benefits

Figure 4.5 shows additional information on the behavior of average travel time experienced by equipped and non-equipped vehicles as larger numbers of drivers have access and use RGS. The average trip time of non-equipped vehicles is shown to decrease, suggesting that these vehicles benefit from the fact that guided vehicles make better route decision choices. The average trip time of guided vehicles is always lower than the average trip time of non-equipped vehicles. The difference in average trip times is on the order of 0.1 minute for an average trip time of approximately 6.6 minutes.

4.10 Conclusions

This chapter presented the initial results obtained when modelling various control strategies on the Santa Monica freeway corridor during typical incident-free morning peak period traffic conditions. A number of assumptions had to be made in the simulation study, and it was recognized that the modelling results had to be viewed with some caution. In particular, the ramp metering and signal optimization strategies that were simulated could not be regarded as true optimal strategies.

The best system performance in terms of total trip time was obtained when a combination of ramp metering, signal optimization, and **RGS** was implemented. **A** maximum overall trip time savings of 6.1% was achieved in this case, which can be considered as fairly low benefits.

However, a number of possible reasons can be used to explain this result. The network that was used in this simulation study was probably not large enough to provide many opportunities for routing improvements. Also, most of the drivers using this network during the morning peak period are regular commuters who have acquired a very good knowledge of the network structure and the typical traffic conditions in this area. **As** a consequence, the effect of providing these drivers with real-time traffic information under recurring congestion conditions could be expected to be only marginal.

It should be emphasized that the main objective of this phase of the project was related to methodologies rather than numerical results. On the one hand, these ATMS/ATIS strategies could be simulated with the **INTEGRATION** model. On the other hand, these strategies were not fully optimized. **As** indicated in the title of this paper, these investigations and results should be considered as preliminary.

Table 4.1: No Incident

Summary of Results

		SCENARIO 1	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5	SCENARIO 6
Total Travel Distance (veh.km)	Fre	664641	666951	657531	660957	668567	661101
	Ra	72783	70731	72152	59002	58961	57591
	Art	152873	153815	158828	171037	160675	170354
	Ov	1030390	1031681	1028390	1030908	1027892	1028728
Total Trip Time (veh.hrs)	Fre	11304	10617	11240	10675	10980	10072
	Ra	2380	2426	2289	1914	1743	1730
	Art	5561	5778	5450	6189	5628	6108
	Ov	21228	20850	20962	20879	20424	19926
Average Speed (km/h)	Fre	58.8	62.8	58.5	61.9	60.9	65.6
	Ra	30.6	29.2	31.5	30.8	33.8	33.3
	Art	27.5	26.6	29.1	27.6	28.6	27.9
	Ov	48.5	49.5	49.1	49.4	50.5	51.6
Difference in Total Travel Distance (veh.km)	Fre	0	2310	-7110	-3684	3926	-3540
	Ra	0	-2052	-631	-13781	-13822	-15192
	Art	0	942	5955	18164	7802	17481
	Ov	0	1291	-2000	518	-2498	-1662
Difference in Total Trip Time (veh.hrs)	Fre	0	-687	-64	-629	-324	-1232
	Ra	0	46	-91	-466	-637	-650
	Art	0	217	-111	628	67	547
	Ov	0	-378	-266	-349	-804	-1302
Difference in Average Speed (km/h)	Fre	0.0	4.0	-0.3	3.1	2.1	6.8
	Ra	0.0	-1.4	0.9	0.2	3.2	2.7
	Art	0.0	-0.9	1.7	0.1	1.1	0.4
	Ov	0.0	0.9	0.5	0.9	1.8	3.1
Percent Change in Travel Distance	Fre	0.0	0.3	-1.1	-0.6	0.6	-0.5
	Ra	0.0	-2.8	-0.9	-18.9	-19.0	-20.9
	Art	0.0	0.6	3.9	11.9	5.1	11.4
	Ov	0.0	0.1	-0.2	0.1	-0.2	-0.2
Percent Change in Trip Time	Fre	0.0	-6.1	-0.6	-5.6	-2.9	-10.9
	Ra	0.0	1.9	-3.8	-19.6	-26.8	-27.3
	Art	0.0	3.9	-2.0	11.3	1.2	9.8
	Ov	0.0	-1.8	-1.3	-1.6	-3.8	-6.1
Percent Change in Average Speed	Fre	0.0	6.8	-0.5	5.3	3.6	11.6
	Ra	0.0	-4.7	3.1	0.7	10.5	8.9
	Art	0.0	-3.2	6.0	0.4	4.0	1.5
	Ov	0.0	1.9	1.1	1.8	3.6	6.3

Fre: Freeways Ra: Ramps Art: Arterials Ov: Overall

Figure 4.1 : No Incident

Changes in Trip Times

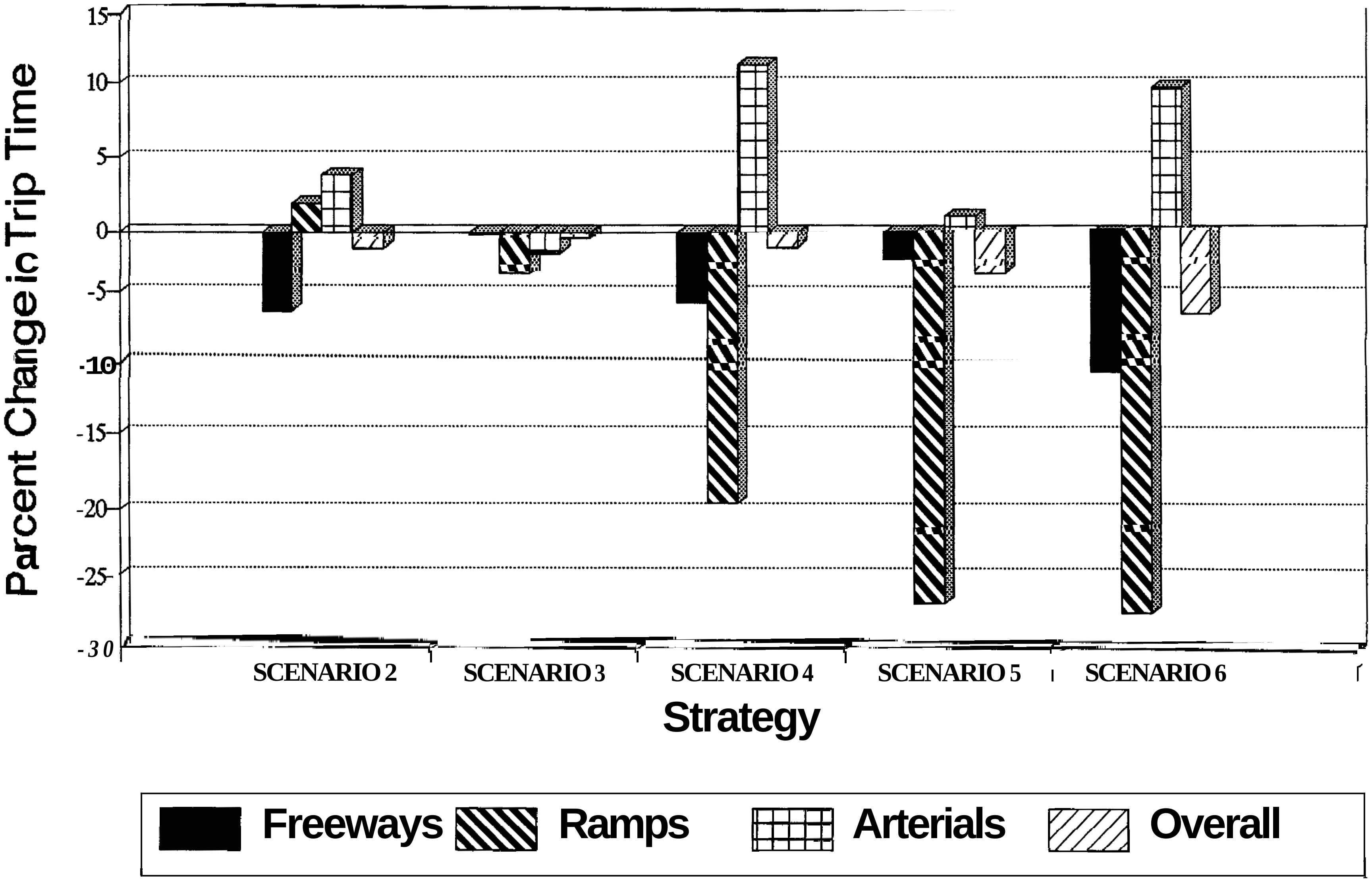


Figure 4.2: No Incident

Changes in Travel **Distances**

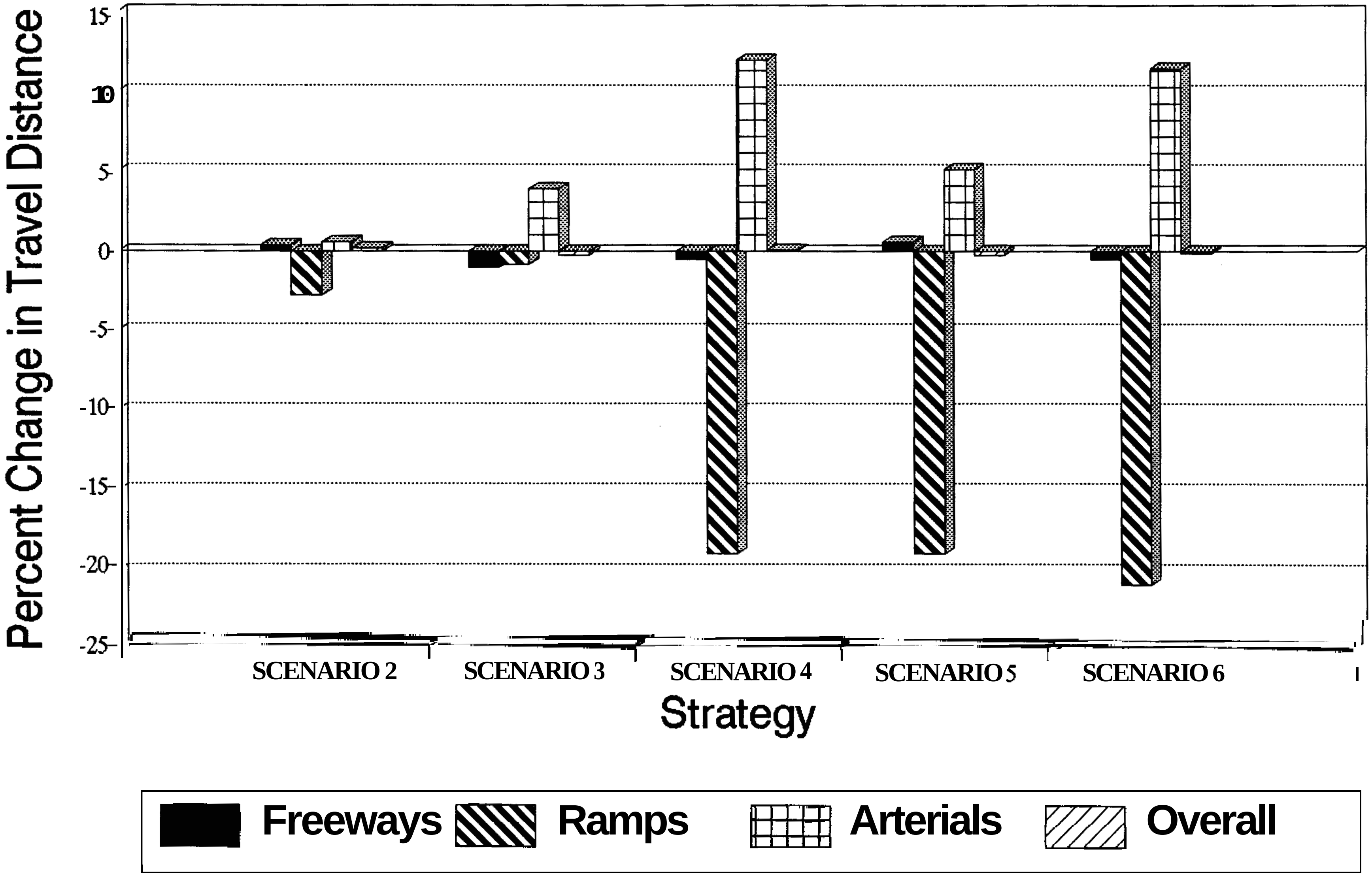


Figure 4.3 No Incident

Changes in Average Speeds

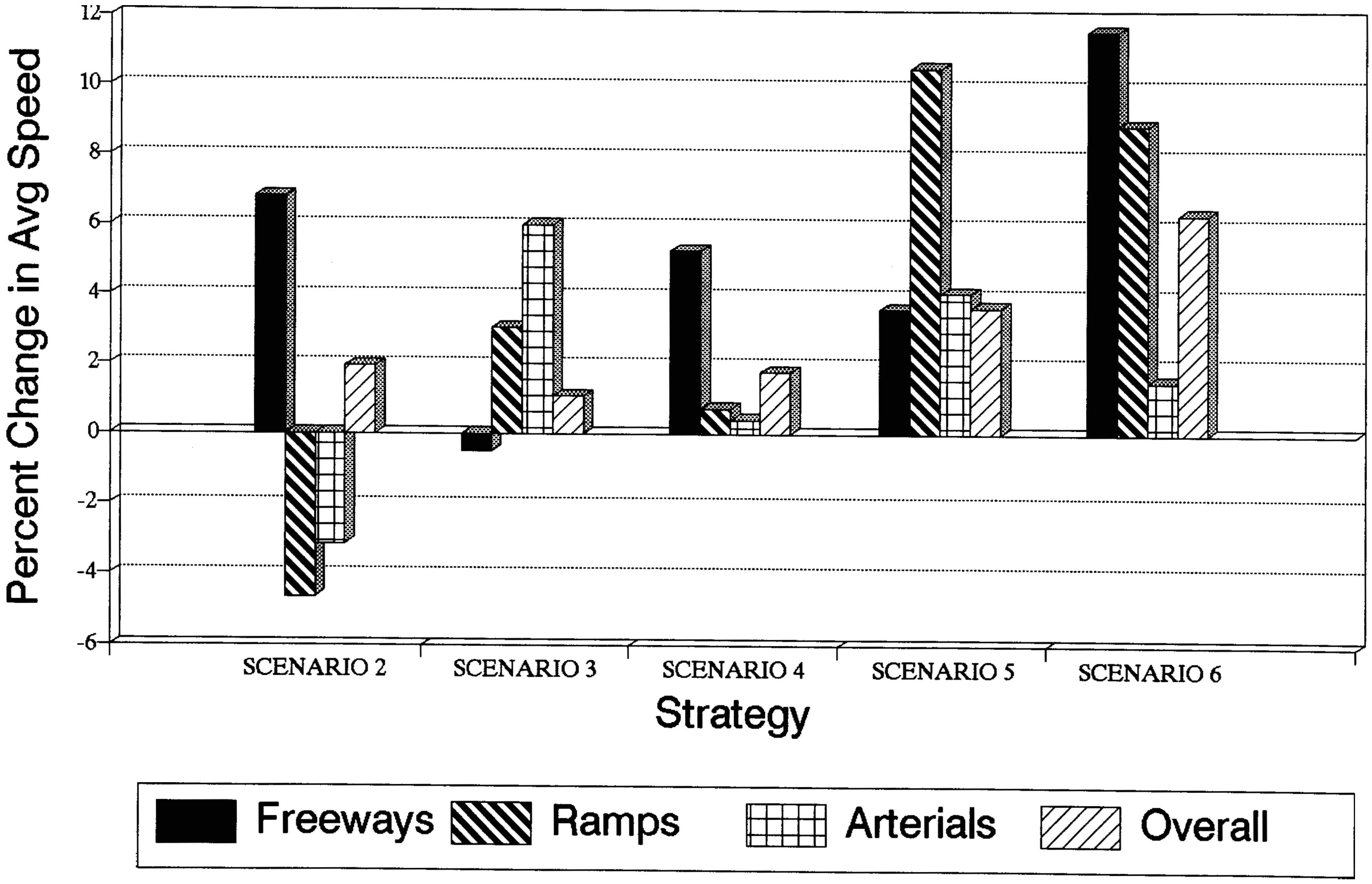


Figure 4.4: System Benefits

Total Trip Time and Percent Savings

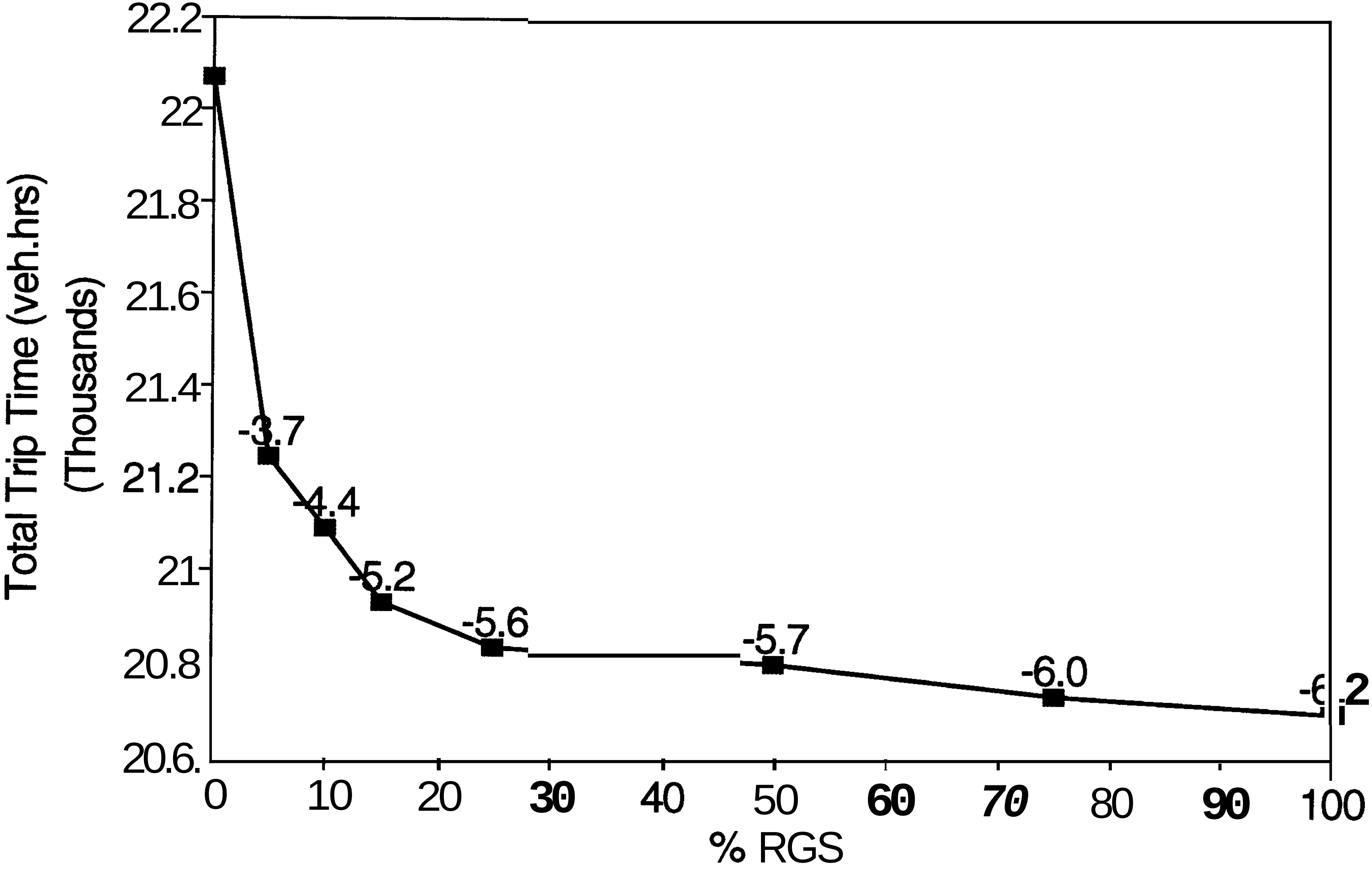
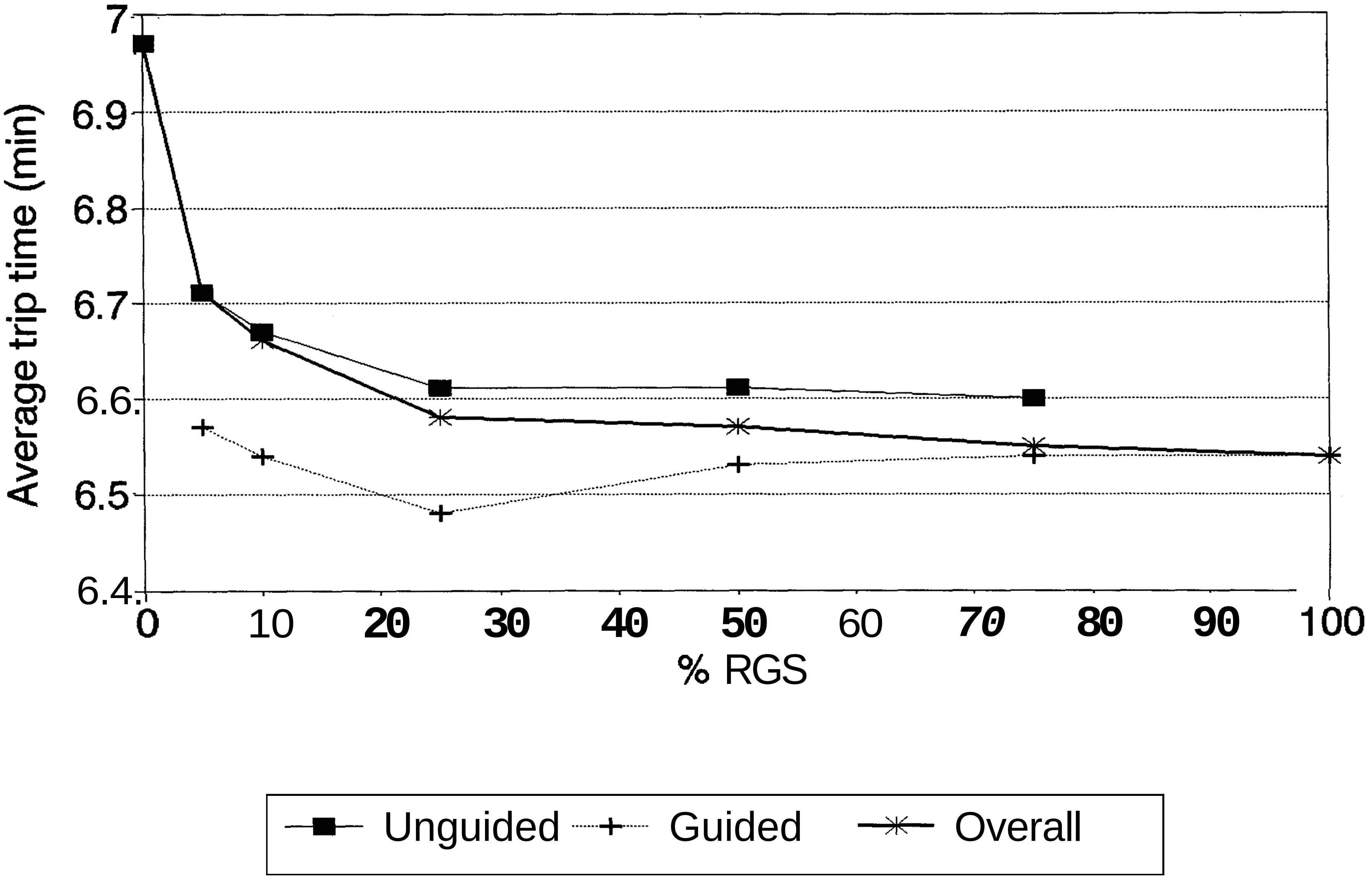


Figure 4.5: User Benefits

Comparison of Average Trip Times



5. INVESTIGATIONS UNDER INCIDENT CONDITIONS

This chapter presents initial results obtained when simulating various ATMS and ATIS strategies on the coded portion of the Santa Monica freeway corridor, under an incident condition. The objective was to evaluate the potential benefits of different control strategies under an incident condition, and to compare the results with the no-incident case described in Chapter 4 of this report.

5.1 Design of Experiment

The different control strategies to be tested under incident conditions include all the strategies previously modelled under incident-free conditions, namely: no ATMS or **ATIS** (Scenario 7); ramp metering only (Scenario 8) ; signal optimization only (Scenario 9); combination of ramp metering and signal optimization (Scenario 10); route guidance systems (Scenario 11); combination of ramp metering, signal optimization and route guidance systems (Scenario 12). In addition, another scenario was developed to represent a combination of route guidance and signal optimization (Scenario 13).

The incident file was created with the following attributes: incidents were assumed to occur at the same time in each direction of the freeway. On the eastbound direction, the incident occurs just after the Normandie interchange; on the westbound direction, the incident is located between the Arlington and Creenshaw interchanges. In both cases, two lanes were blocked between 7:00 **AM** and 7:30 AM.

Simulation results under incident conditions are presented in this chapter under the same format as in Chapter 4. A tabular summary of results is provided in Table 5.1 while some graphical analyses are shown in Figures 5.1, 5.2 and 5.3. Again, the quantitative results presented and discussed in this chapter represent only initial findings and will have to be confirmed by further research.

5.2 Scenario 7: Base Incident

The first column of Table 5.1 indicates the total travel distance, total trip time and average speed predicted by the simulation model after introducing the incident without ATMS/ATIS strategies. From these figures and those given in Table 4.1, it is possible to evaluate the overall direct effect of the incident. In terms of total trip time, the incident resulted in an additional trip time of **2356** veh.hrs (+11%). The incident also caused a reduction of the network average speed from 48.5 km/h to 43.8 km/h.

5.3 Scenario 8: Ramp Metering

The ramp metering plan implemented in this scenario was the same as the one previously used in the no-incident case (eastbound direction only), It was recognized in Chapter 4 that this metering plan could not be considered as the optimum plan under incident-free conditions. The metering plan was not modified in response to the new traffic conditions resulting from the introduction of the incident. **As** a consequence, it was intuitively thought that this control strategy could not produce significant benefits.

The results shown in Table 5.1 suggest that the implementation of this particular ramp metering strategy actually produced a deterioration in the system performance both in terms of total trip time (+3%) and network average speed (-3%). These results were not totally unexpected and confirmed the intuitive idea that implementing a metering plan developed for a typical day of operation can have some adverse effects on system performance when incidents occur.

5.4 Scenario 9: Signal Optimization

The signal optimization strategy modelled in this case was the same as the one previously described and modelled under no-incident conditions. It consisted of a dynamic optimization of splits and cycle lengths at individual signalized intersections, with no attempt to dynamically optimize the coordination of signals along the arterials or the signal phasing.

The results of this control strategy is shown in Table 5.1 to produce some benefits: the total trip time was reduced by 5.6% and the network average speed was increased by 5.6%. Contrary to the ramp metering strategy modelled in Scenario **8,** this control strategy is responsive to the new traffic conditions resulting from the introduction of the incident.

It is interesting to notice that the benefits of signal optimization are shown to be greater in the incident case than in the no-incident case. For instance, under no-incident conditions, Scenario **3** resulted in a total trip time decrease of only 1.3%. This can be explained by looking at the travel distances by link type. In the no-incident case, the arterials accounted for **158,828** veh.km whereas in the incident case, a total travel distance of 173,171 veh.km was experienced on the arterials. This increase in the distance travelled on the arterials (+9%) suggests that more traffic had been routed to the freeway/ramp system. The arterials seemed to have the ability to accommodate the additional traffic, as evidenced by the fact that the average arterial speed was not reduced.

5.5 Scenario 10: Combined Ramp Metering and Signal Optimization

This scenario resulted in a trip time reduction of 3.1% and an average speed increase of 3.6%. These results are not as good as those observed in Scenario 9 when testing signal optimization only. This can be explained by the limitations of the ramp metering plan that were already discussed in Section 5.3.

On the other hand, the benefits of this control strategy under the incident case are again shown to be better than under no-incident conditions. This can also be explained by the fact that more vehicles were assigned to the freeway/ramps after the incident occurs, and the additional traffic on the arterials can be accommodated without serious deterioration of traffic performance when the real-time signal optimization is used.

5.6 Scenario 11: Route Guidance Systems

When modelling RGS only *(25%* equipment rate), the system experienced improvements in total trip time (-5.3%)and average network speed (+5.4%). The magnitude of the benefits are similar to those observed in Scenario 9 with signal optimization only. However, the benefits of **RGS** do not seem to result from the same route choice pattern. When comparing the changes in trip times per link type in Scenarios 9 and 11, it appears that Scenario 9 was particularly good for the arterials whereas Scenario 11 resulted in higher improvements on the freeway side. In Scenario 11, the arterial trip time is shown to increase, suggesting that some traffic had been routed to the freeway/ramp system, but that this additional traffic could not be accommodated by the arterials without causing increased delays. The benefits of **RGS** were primarily experienced on the freeway.

5.7 Scenario 12: Combined Ramp Metering, Signal Optimization and RGS

In this scenario, the three control strategies were simultaneously used. This scenario gave the best overall system performance in the no-incident case (see Scenario 6). Under incident conditions, however, Table 5.1 indicates that the benefits of this strategy are slightly lower than those obtained in Scenarios 9 and 11. This can be attributed to the poor ramp metering strategy implemented in Scenario 12, as was the case in Scenarios 8 and 10.

The diversion pattern is similar to what was observed in Scenario 10, showing a significant increase in travel distance on the arterials and decrease in travel distance on the freeway. As a result of this diversion process, the freeway experienced high benefits (-16.9% in trip time), but at the same time, the arterial trip time increased by 16.7%.

5.8 Scenario 13: Combined Signal Optimization and RGS

Because of the problems related to the metering plan, it was thought that testing **an** additional scenario without ramp metering could be of interest. Indeed, Scenario 13 is shown in Table 5.1 to produce the best overall results in the incident case. The magnitude of the overall trip time savings (more than 10% in this case) suggests that some significant improvements can be expected from the introduction of ATMS and ATIS, when the strategies are carefully selected and implemented.

It is interesting to notice that the overall network trip time experienced in Scenario 13 (in presence of two severe freeway incidents) is 21,163 veh.hrs, whereas the base case (Scenario 1) produced an overall trip time of 21,228 veh.hrs. Scenario 13 showed benefits for all link types, as the freeway average speed was increased by 15.3% while the arterial average speed was increased by 10.1%.

5.9 Route Choice Analysis

This section presents an analysis of the impact of incidents and different control strategies on the route choice pattern. It was anticipated that the introduction of incidents on the freeway and/or the introduction of **RGS** would cause some traffic to be more balanced between the freeway and the parallel arterials, reflecting an effort by travelers to lower their travel times. In order to confirm this theory, traffic flows on Adams Boulevard (see Figure 2.1) were compared under several incident/control strategy scenarios. The intersections of Western Ave and Normandie

Ave, in the eastbound direction were chosen as sites to study traffic flows on Adams Blvd. This choice was made based on the incident location, which was previously selected to occur on the freeway eastbound direction at the Normandie interchange.

5.9.1 Effect of Incident

Figure 5.4 compares traffic flows on Adams Blvd with and without incidents on the freeway. The flows are aggregated by 15-minute time slices. The incident starts at 7:00 AM and ends at 7:30 **AM.** In both the incident and no-incident cases, the results were obtained for the same control strategy, namely combined ramp metering, signal optimization and **RGS.**

Figure 5.4 indicates that, after the incident occurs on the freeway, the flows on Adams Blvd are always higher in the incident scenario. This confirms the intuitive idea that the **RGS** provides an incentive for equipped drivers to shift route from the freeway to the parallel arterials because of the increased freeway travel time induced by the incident. The variation in volumes in the two scenarios reaches a maximum of 800 veh/hr at 7:30 AM, which corresponds to the incident ending time and the maximum incident-induced delay on the freeway.

*5.9.2 Effect of **RGS** and ATMS*

In order to evaluate the impact of **RGS** equipment on the route choice pattern, flows on Adams were compared in two scenarios: under incident conditions, with **RGS** (Scenario 11) and without **RGS** (Scenario 7). Figure 5.5 indicates that the introduction of **RGS** by itself did not induce any significant changes in the diversion pattern. This may be explained by the fact that if the arterial signal timings are not dynamically responsive to changes in traffic flows, there is little (or no) travel time benefits to be expected by balancing traffic between the freeway and the surface streets. Another possible reason is the fact that even under base incident conditions, vehicles are modelled as having access to some form of en-route information (see Section 3.4); therefore the introduction of **RGS** by itself does not provide any additional changes in the diversion pattern.

When combining **RGS** and ATMS (ramp metering and signal optimization), Figure 5.5 indicates that the flows on Adams Blvd were consistently higher after 6:45 AM when ATMS are used. This seems to confirm the fact that the modelled signal optimization strategy provides an incentive for drivers to shift route from the freeway to the surface streets. The difference in flows compared to the base case can be as high as 1600 veh/hrs (at 8;45 AM).

5.10 Conclusions

This chapter described the results of various ATMS and ATIS control strategies under incident conditions. It was recognized that the tested control strategies could not be considered as the true optimal strategies, and therefore, the results should be viewed with some caution. Also, as previously mentioned, focus of this study was more on testing modelling methods than producing numerical results.

The ramp metering strategy used in Scenarios 8, 10 and 12 was found to be of little benefit (if any) to the system performance. This was attributed to the fact that the metering plan was developed for incident-free conditions and was not modified after the incident occurred. This suggests that one has to be careful when operating ramp control under non-recurring congestion and that sometimes, no control is better than using a poor control strategy.

On the other hand, the modelled signal optimization and RGS strategies were found to be very helpful under incident conditions. These control strategies present the advantage of being traffic-responsive. The overall savings obtained in Scenario 13 (overall system trip time reduced by more than 10%) are encouraging. In this case, the system was actually found to perform better than under base incident-free conditions.

Table 5.1: Incident Case

Summary of Results

		SCENARIO 7	SCENARIO 8	SCENARIO 9	SCENARIO 10	SCENARIO 11	SCENARIO 12	SCENARIO 13
Total Travel Distance (veh.km)	Fre	665986	661736	656953	653392	664676	645468	655668
	Ra	60487	60463	59134	59689	60094	59223	58859
	Art	165540	172532	173171	181960	166221	188176	173704
	Ov	1032048	1034562	1029010	1035088	1030740	1032440	1027963
Total Trip lime (veh.hrs)	Fre	13150	12793	12188	11315	12034	10923	11232
	Ra	1908	1966	1811	2065	1841	2007	1791
	Art	6327	7496	6131	7164	6378	7385	6035
	Ov	23584	24291	22263	22842	22345	22477	21163
Average Speed (km/h)	Fre	50.6	51.7	53.9	57.7	55.2	59.1	58.4
	Ra	31.7	30.8	326	28.9	326	29.5	329
	Art	26.2	23.0	28.2	25.4	26.1	25.5	28.8
		43.8	42.6	46.2	45.3	46.1	45.9	48.6
Difference in Total Travel Distance (veh.km)	Fre	*0*	-4250	-9033	-12595	-1311	-20518	-10318
	Ra	*0*	-24	-1353	-797	-393	-1264	-1628
	Art	*0*	6993	7631	16420	681	22636	8164
	Ov	0	2514	-3038	3040	-1309	392	-4085
Difference in Total Trip Time (veh.hrs)	Fre	*0*	-357	*-962*	-1835	-1116	-2227	-1918
	Ra	0	58	-97	157	-67	98	-117
	Art	0	1169	-196	837	51	1058	-292
	Ov	0	707	-1321	-742	-1239	-1106	-2421
Difference in Average Speed (km/h)	Fre	0.0	1.1	3.3	7.1	4.6	8.4	7.8
	Ra	0.0	-0.9	0.9	-2.8	0.9	-2.2	1.2
	Art	0.0	-3.1	2.1	-0.8	-0.1	-0.7	2.6
	Ov	0.0	-1.2	2.5	1.6	2.4	2.2	4.8
Percent Change in Travel Distance	Fre	0.0	-0.6	-1.4	-1.9	-0.2	-3.1	-1.5
	Ra	0.0	-0.0	-2.2	-1.3	-0.6	-2.1	-2.7
	Art	0.0	4.2	4.6	9.9	0.4	13.7	4.9
	Ov	0.0	0.2	-0.3	0.3	-0.1	0.0	-0.4
Percent Change in Trip Time	Fre	0.0	-2.7	-7.3	-14.0	-8.5	-16.9	-14.6
	Ra	0.0	3.0	-5.1	8.2	-3.5	5.1	-6.1
	Art	0.0	18.5	-3.1	13.2	0.8	16.7	-4.6
	Ov	0.0	3.0	-5.6	-3.1	-5.3	-4.7	-10.3
Percent Change in Average Speed	Fre	0.0	2.1	6.4	14.0	9.1	16.7	15.3
	Ra	0.0	-3.0	3.0	-8.8	3.0	-6.9	3.8
	Art	0.0	-12.0	7.9	-2.9	-0.4	-2.6	10.1
	Ov	0.0	-2.7	5.6	3.6	5.4	5.0	11.1

Fre: Freeways Ra: Ramps *Art:* Arterials Ov: Overall

Figure 5.1: Incident Case

Changes in Trip Times

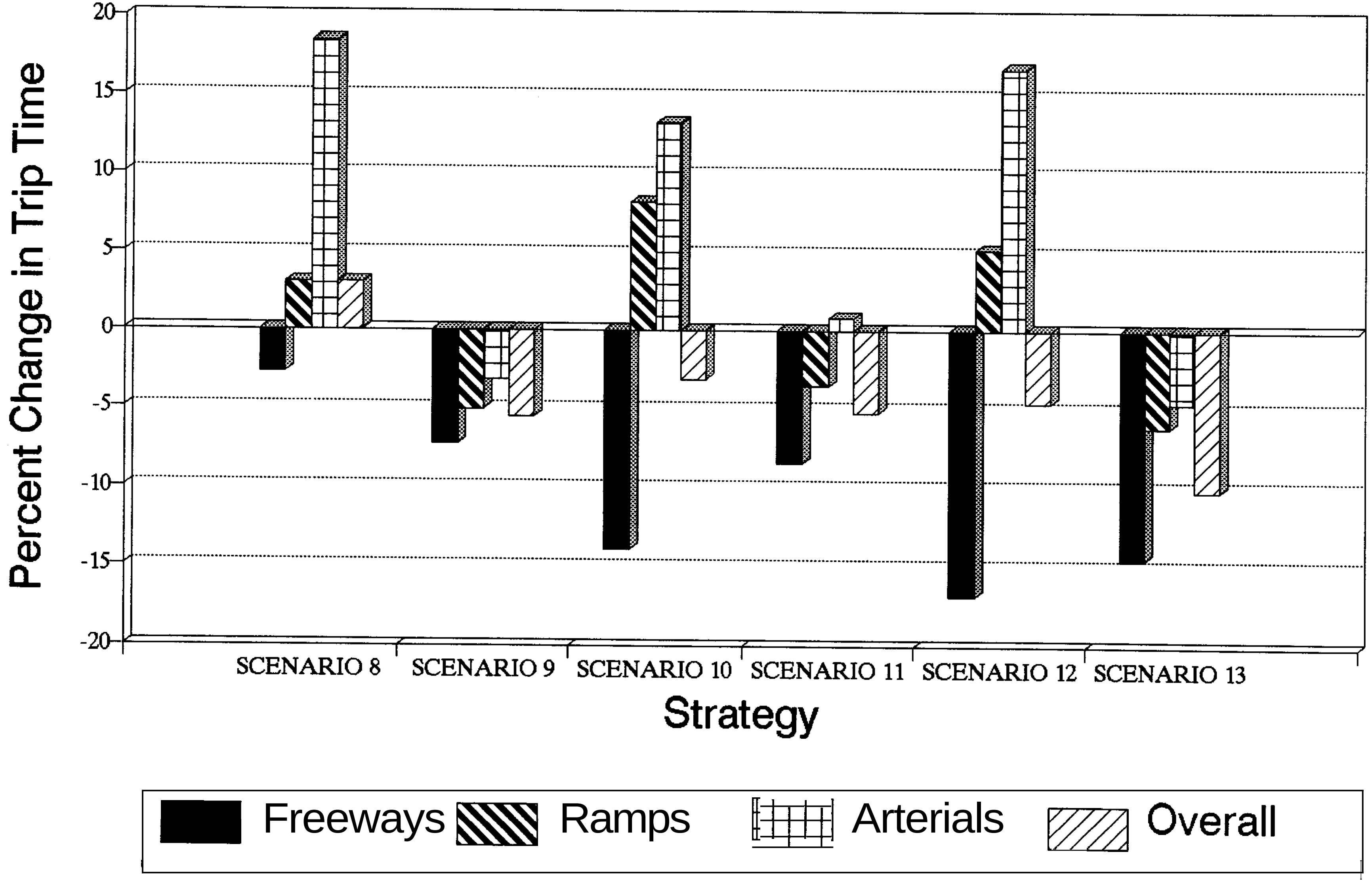


Figure 5.2: Incident Case

Changes in Travel Distances

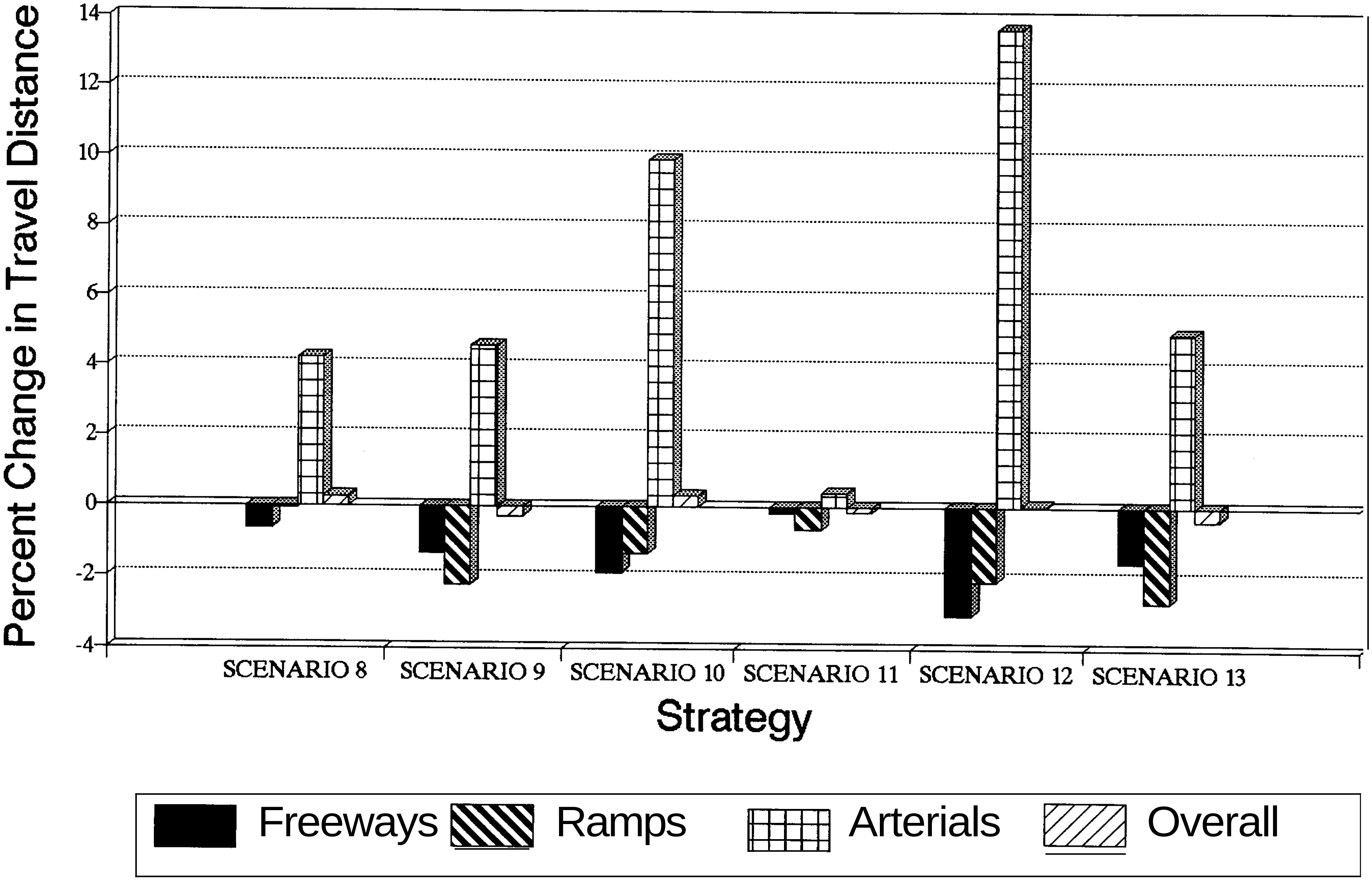


Figure 5.3: Incident Case

Changes in Average Speeds

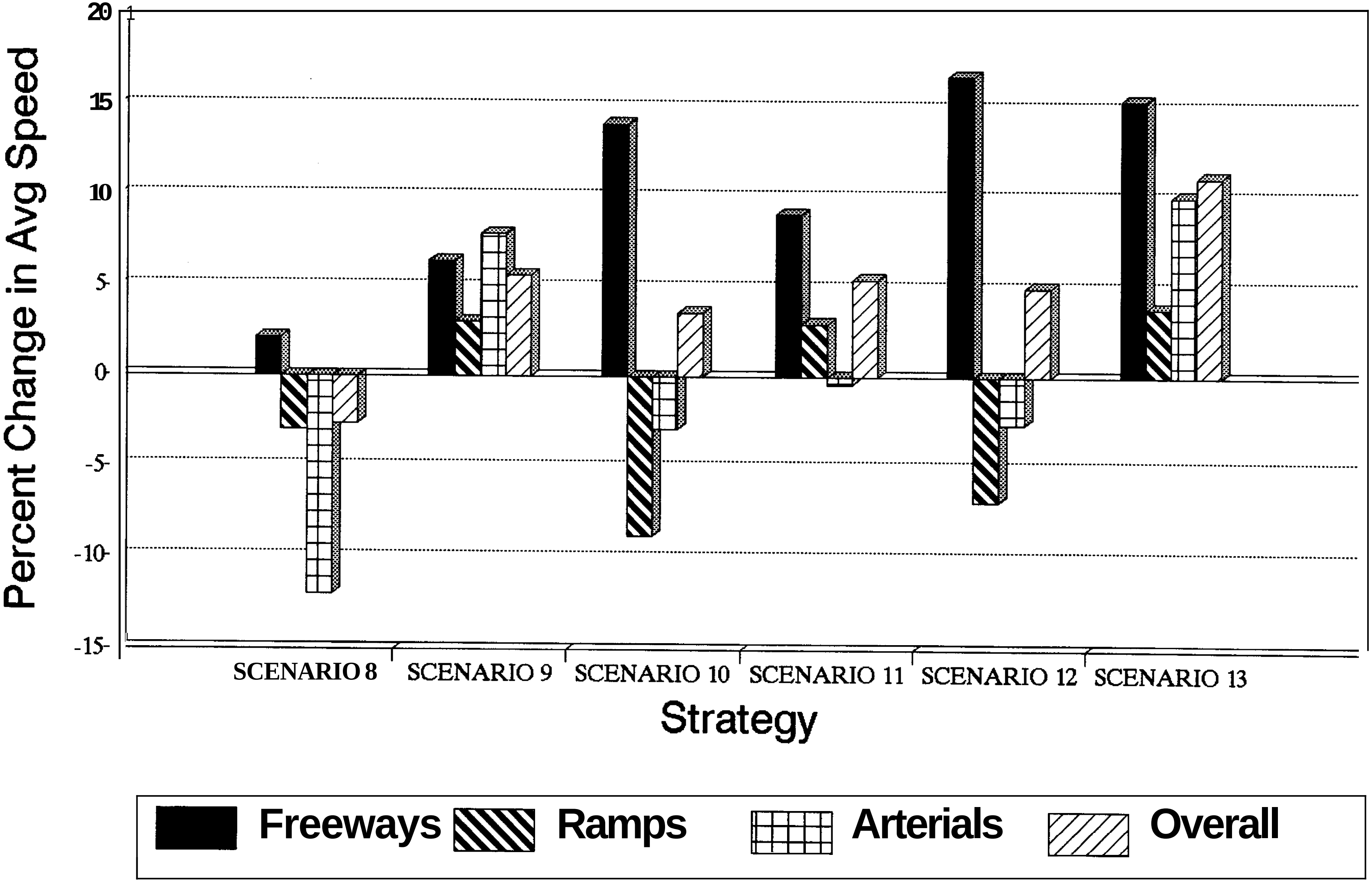


Figure 5.4: Route Choice Analysis

Effect of incident

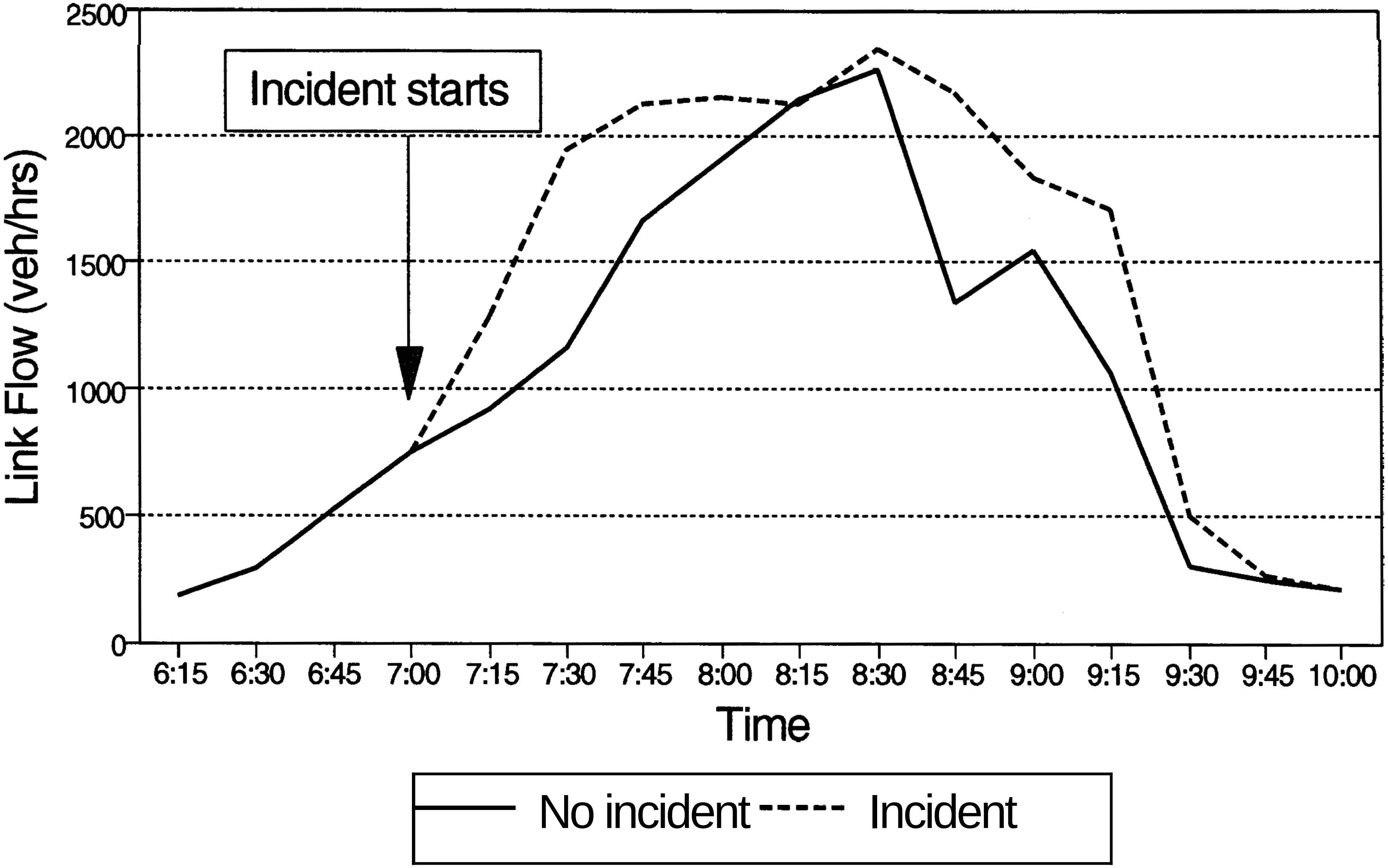
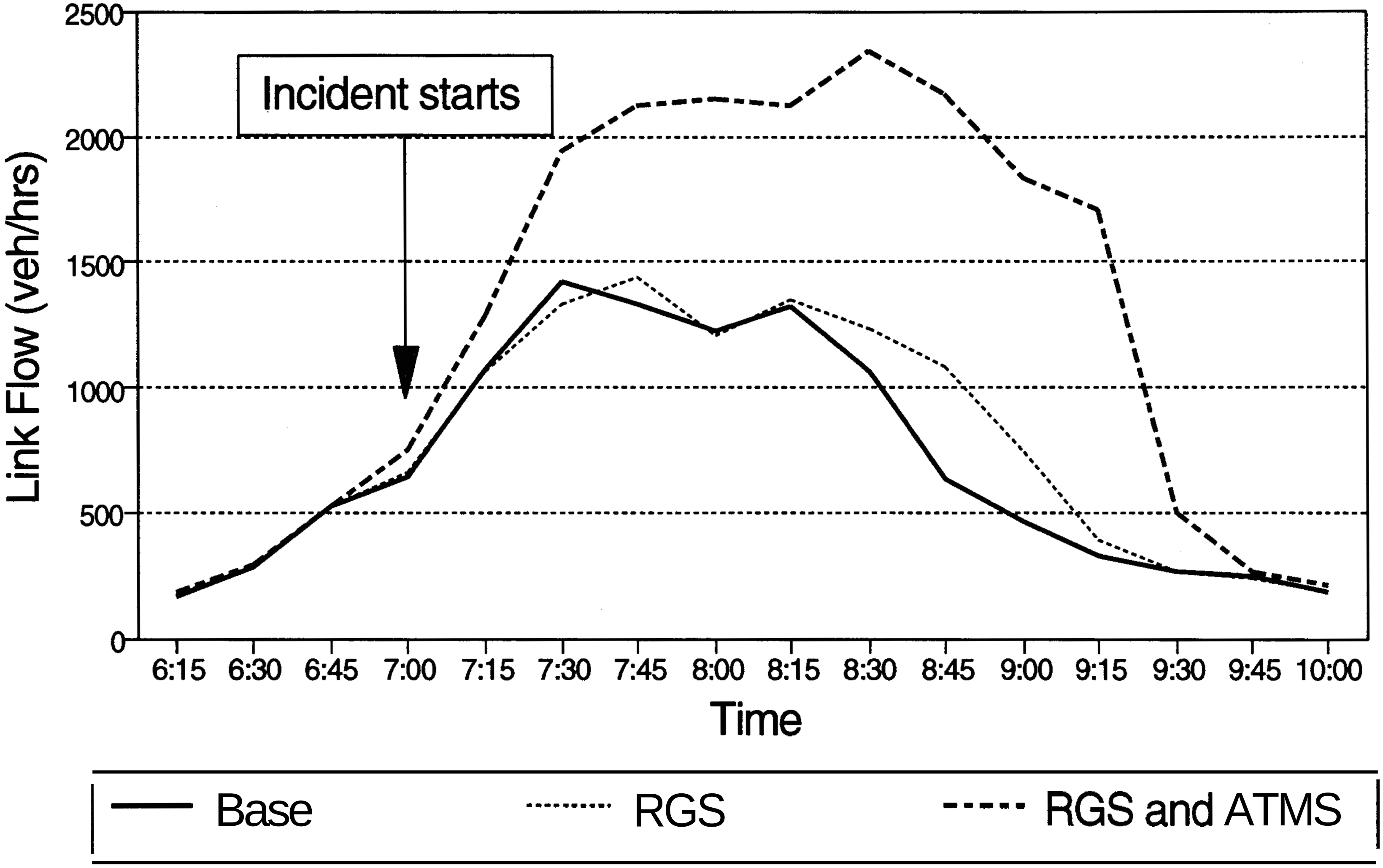


Figure 5.5: Route Choice Analysis

Effect of RGS and ATMS



6. CONCLUSIONS

The primary objective of this phase of the project has been to assess the capabilities of the INTEGRATION model to simulate a variety of ATMS and ATIS strategies. The simulations are ultimately used to evaluate these strategies independently and in various combinations under recurring and non-recurring conditions. Particular attention was given to ramp metering, signal timing, in-vehicle information, and incident simulation. In the process, issues were raised in regard to generating of synthetic origin-destination tables, modelling on-freeway high-occupancy vehicle lanes, modelling CMS and HAR strategies, and analyzing complex traffic performance results.

6.1 Ramp Metering

Ramp metering was successfully simulated with the INTEGRATION model. Metering rates could be varied over time and between ramps, and one vehicle per green metering could be modelled. However, in the current version of the INTEGRATION model the user must specify the metering rate for each ramp in each time period. The transport of an optimum metering plan derived from another simulation model was only partially satisfactory. Under incident conditions, using a metering plan derived outside of INTEGRATION is even less appropriate.

Research is needed to develop and incorporate an optimum metering rate algorithm within the INTEGRATION model. This may take the form of linear programming formulations such as used in the FREQ model, or some form of an extended local traffic-responsive formulation.

6.2 Signal Timing

Signal timing plans were successfully simulated with the INTEGRATION model. Signal timing plans could be varied over time and between intersections. In the current version of the INTEGRATION model the user may either specify the signal timing plan for each time slice and intersection, or can engage a form of traffic-responsive signal timing optimization. This can include adjusting the phase lengths and cycle lengths for each individual intersection. Such optimization does not include offset optimization with a common cycle length, nor the optimization of the number and sequence of phases.

Research is needed to develop and incorporate an optimal signal timing algorithm with the INTEGRATION model. This may take the form of the SCOOT model or extended versions of such models as TRANSYT or PASSER.

6.3 Route Guidance Systems

Route guidance systems were successfully simulated with the INTEGRATION model. Two types of driver-vehicle types were modelled. Both unguided and guided vehicles were modelled using the same vehicle type within the model, but the guided vehicles were provided with more accurate and more frequently updated traffic information. The difficulty arose in setting appropriate parameter values for each class of vehicle. The complexity of the network characteristics made it difficult to completely verify resulting traffic routings and traffic performance.

Research is needed to verify traffic routings of guided and unguided vehicles. Different routing options available within INTEGRATION for modeling guided and unguided vehicles should be further tested. This research should be first directed to applications with simple networks and in-vehicle information parameter values with greater in-depth analyses of results.

6.4 Incident Simulation

Freeway incidents were successfully simulated with the INTEGRATION model. Two incidents with specified locations, time durations, and reduced capacities were modelled. However, research time constraints did not permit extensive investigations of incidents, detailed study of traffic conditions at the incident site, or analyses of upstream queuing.

Research is needed by simulating a wider spectrum of incident situations and by studying in greater depths the traffic conditions at and downstream of the incident site.

6.5 Synthetic O-D Generation

A series of O-D tables were generated successfully from road counts with the INTEGRATION and QUEENSOD models. When traffic in the O-D table was assigned to routes, predicted counts compared favorably with the origin street counts. However, relatively small differences in freeway flows resulted in some appreciable differences in traffic performance. It should also be noted that only external origin and destination zones were used.

Research is needed to further investigate the synthetic origin and destination algorithm. Some of the directions to be considered include introducing interim O-D zones, comparing freeway O-D tables derived only from freeway data with those derived from corridor data, and studying the sensitivity of generated O-D tables on traffic performance.

6.6 On-Freeway HOV Lanes

Time constraints did not permit the experimentation with nor the evaluation of on-freeway HOV lanes with the INTEGRATION model. Since HOV lanes are an important ATMS strategy, future research should be directed at this topic.

6.7 Modelling CMS and HAR Strategies

The only ATIS strategy investigated in the current study was route guidance systems. Since CMS and HAR strategies are also important ATIS strategies, future research should be directed to this topic.

6.8 Analyzing Model Output

In addition the INTEGRATION model's very effective animation feature, comprehensive traffic performance data are available for each link in each time period. The masses of data, while very complete, proved to be very difficult to utilize effectively in assessing the consequences of various traffic strategies. Research is needed to present the model output in a variety of ways in order to aid the analyst in assessing strategy consequences. This most likely will take the form of aggregating individual link information and a variety of graphical presentations.

6.9 Summary

Much has been learned about the INTEGRATION model. This research has provided further assessment of the capabilities and limitations of the INTEGRATION model, and areas for further research are noted. While there are still some limitations in INTEGRATION, this model still appears to be significantly better for simulating **IVHS** strategies than any known simulation model.

7. REFERENCES

1. H. Al-Deek and A.D. May, "Potential Benefits of In-Vehicle Information Systems: Demand and Incident Sensitivity Analysis", PATH Research Report UCB-ITS-PRR-89-1

2. Y. Gardes and A.D. May, "Traffic Models for Integrated Freeway/Arterial Networks", PATH Research Report UCB-ITS-PRR-90-3

3. Y. Gardes, B. Haldors and A.D. May, "Model Selection and Initial Application of CONTRAM for Evaluating In-Vehicle Information Systems", PATH Research Report UCB-ITS-PRR-91-11

4. Y. Gardes and A.D. May, "Simulation of IVHS on the Smart Corridor Using the INTEGRATION Model - Phase 1: Initial Investigations", PATH Research Report UCB-ITS-PRR-93-3, May 1993

5. Y. Gardes, L. Bloomberg, A.D. May and M. Van Aerde, "Freeway Simulation with the INTEGRATION Model", presented at ITE District 6 Annual Meeting, July 1993

6. Y. Gardes, M. Lunsford, A.D. May and M. Van Aerde, "Application of the INTEGRATION Model to Demonstrate the Simulation of Advanced Traveler Information Systems", TRB Paper No. 930474, January 1993

7. B. Hellinga and M. Van Aerde, "QUEENSOD: A Model for Estimating Static and Dynamic Origin-Destination Traffic Demands - User's Guide to Model Version 1.2", Transportation Systems Research Group, Department of Civil Engineering, Queen's University, Kingston, Canada, May 1992

8. M. Van Aerde, "INTEGRATION: User's Guide for Model Version 1.4 d", Transportation Systems Research Group, Department of Civil Engineering, Queen's University, Kingston, Canada, May 1992

9. A.D. May, "Freeway Simulation Models - Revisted", TRB Freeway Operations Committee Meeting, January 1987

10. C.W. Blumentritt et al., "Guidelines for Selection of Ramp Control Systems", National Cooperative Highway Research Program Report 232, TRB, May 1981

11. H. Rahka, M. Van Aerde and E.R. Case, "Experiments in incremental real-time optimization of phase, cycle, and offset times using an on-line adaptation of TRANSYT-7F", Presented at the Engineering Foundation Conference on 'Traffic Management: Issues and Techniques', Palm Coast, Florida, April 1991