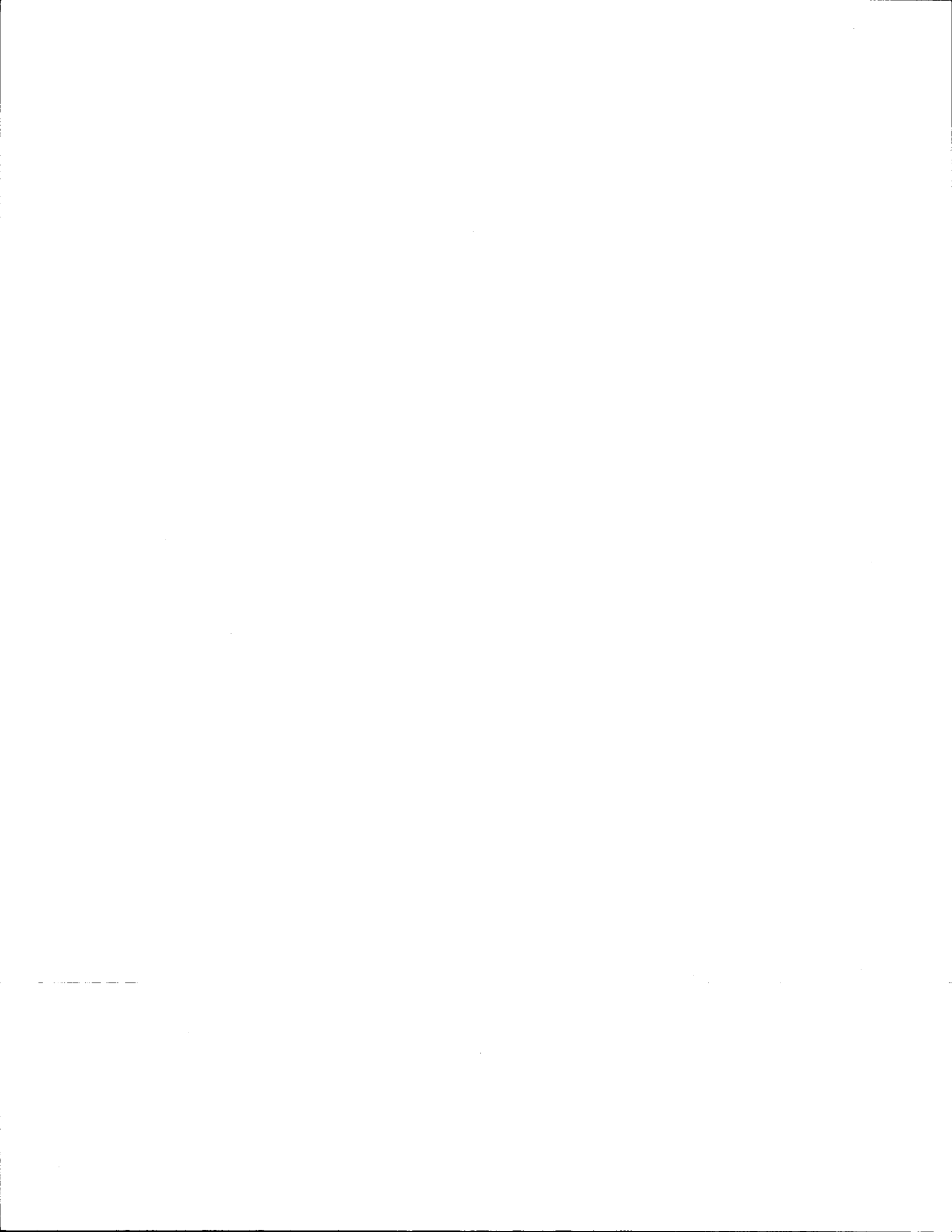


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| 16. Abstract This report provides guidelines on corridor-scale analysis using corridor traffic simulation models to evaluate traffic management alternatives for freeway incidents. It focuses on identifying the analysis requirements for corridor traffic management during freeway incidents and offering guidance on how CORFLO, an available corridor traffic simulation model, can be best used to satisfy those requirements. The analysis requirements when developing corridor incident management strategies are described as the concepts, functions, and capabilities of corridor simulation models. A case study is presented to provide an understanding of the corridor-analysis process, to discuss the difficulties involved, and to suggest the necessary precautions to take during analysis. | | | | | |
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**CORRIDOR ANALYSIS GUIDELINES
FOR INCIDENT MANAGEMENT**

by

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and

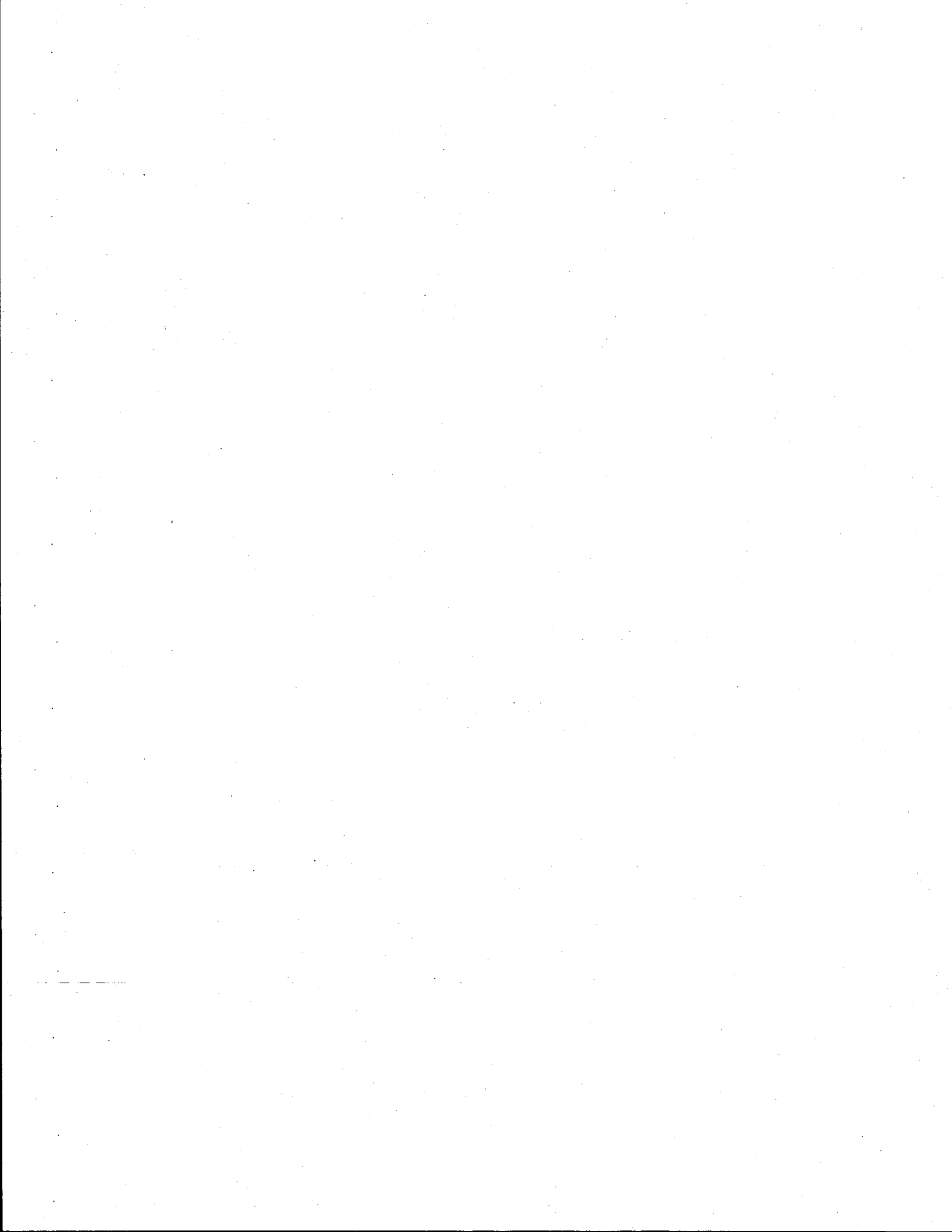
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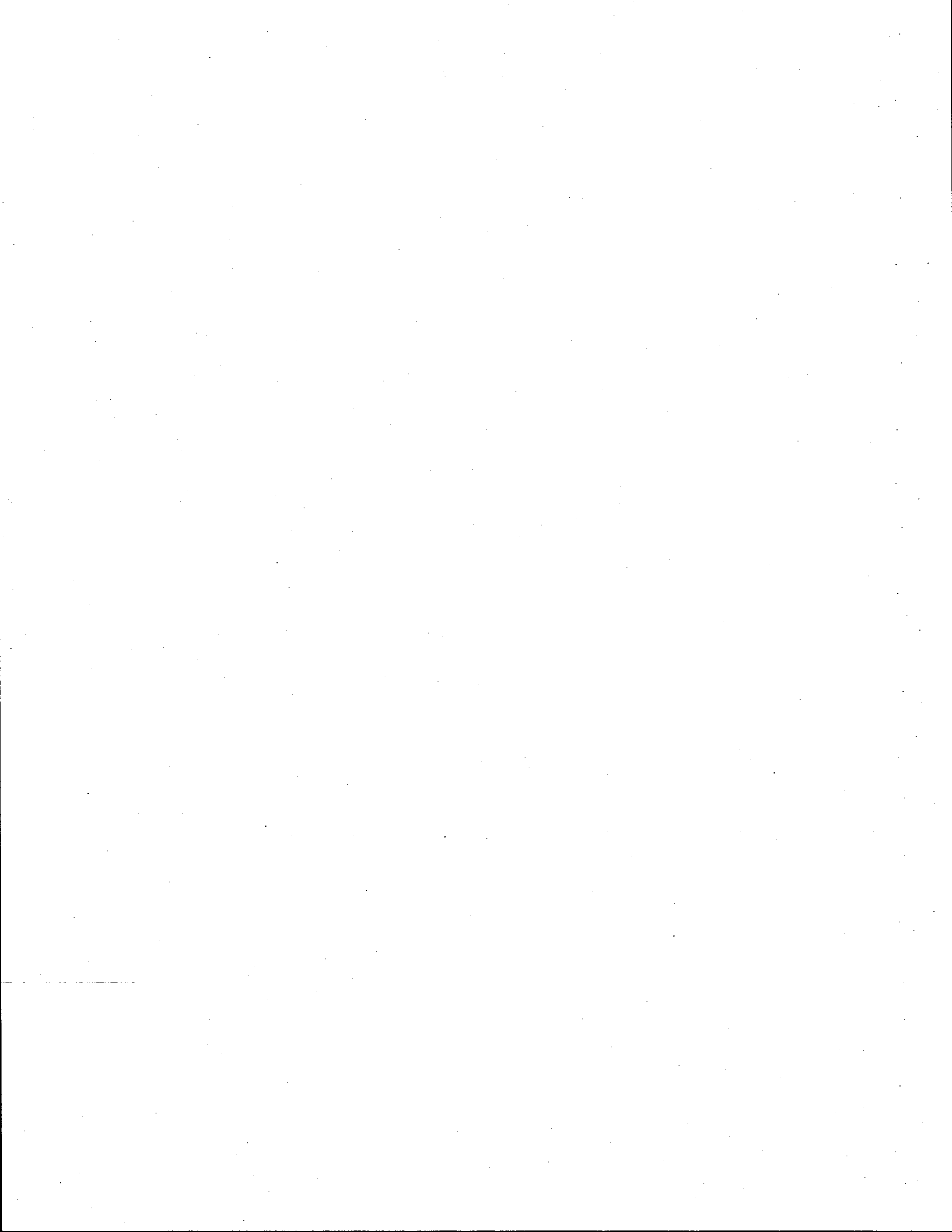
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IMPLEMENTATION STATEMENT

The Texas Department of Transportation is investing considerable effort and resources in improving traffic management capabilities to mitigate the congestion caused by the freeway incident. The findings of this study should be helpful to Texas Department of Transportation personnel who plan, design, and implement traffic management systems and strategies. The guidelines suggested by this report will assist engineers in making the best use of corridor traffic simulation models for corridor analysis of traffic management strategies for freeway incidents.



DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding or permit purposes. The engineer in charge of the project was Raymond A. Krammes, P.E., #66413.

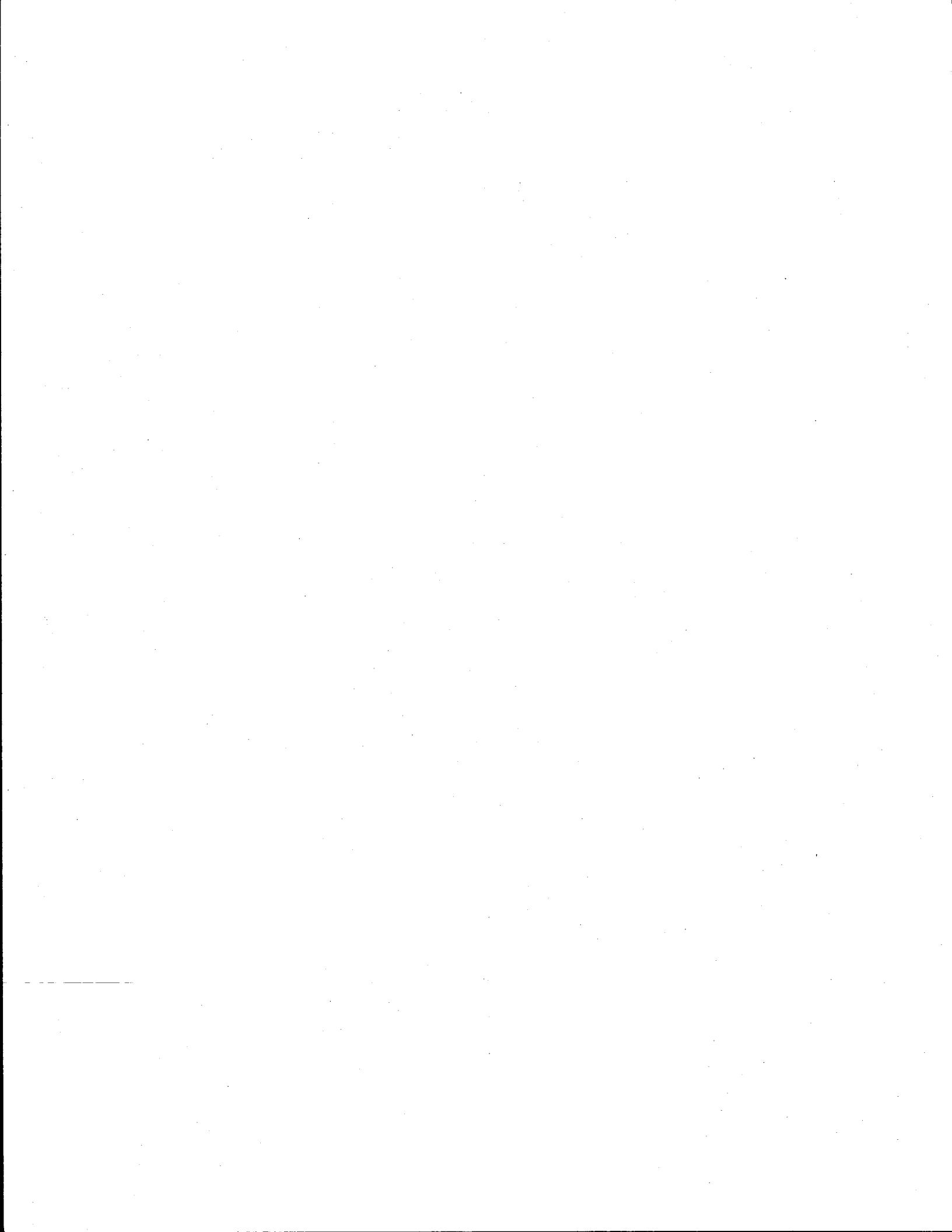


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SUMMARY

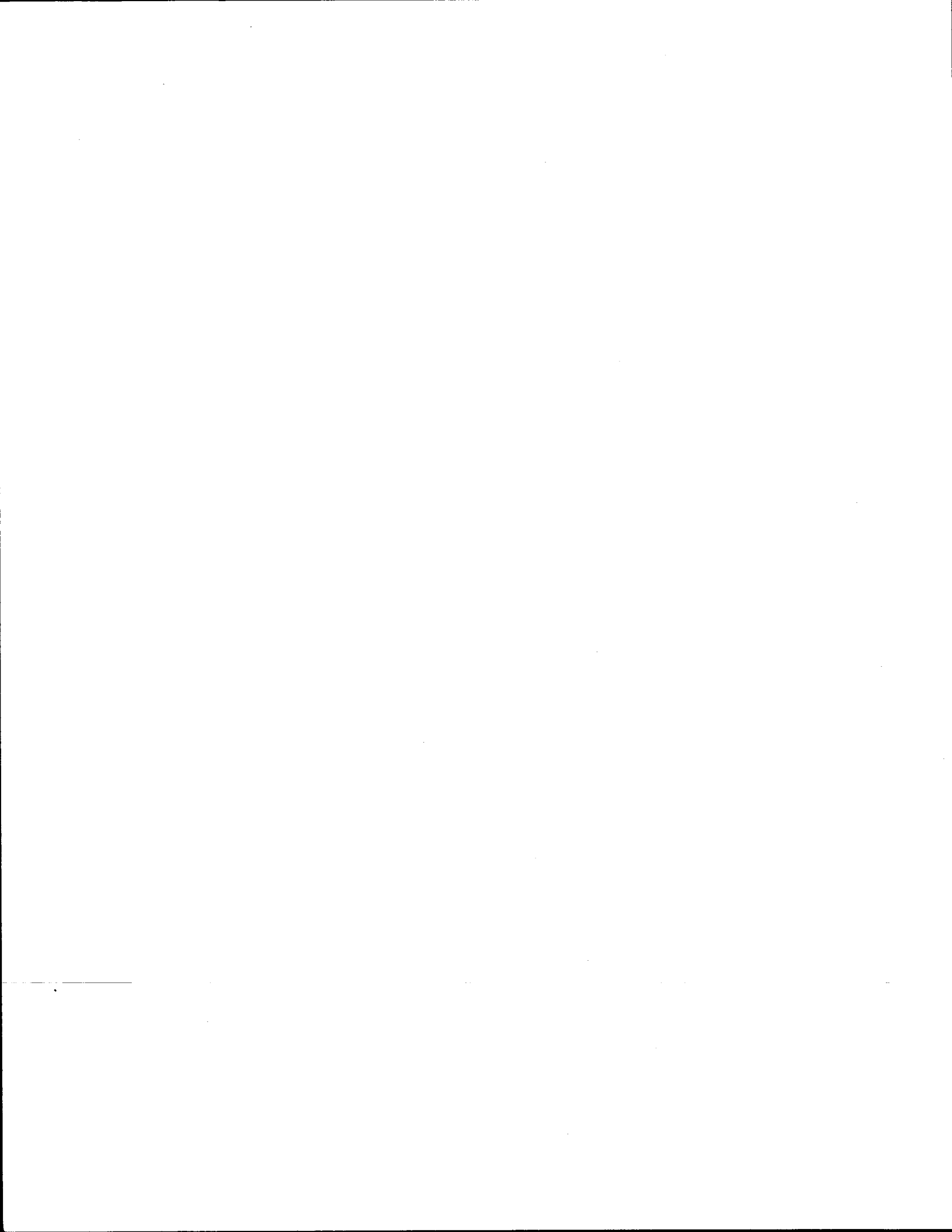
This report provides guidelines on corridor-scale analysis using corridor traffic simulation models to evaluate traffic management alternatives that can be implemented during freeway incidents. The report identifies analysis requirements for corridor traffic management and provides recommendations on how available models can be best used to satisfy those requirements.

Corridor traffic management has the goal of achieving an optimum balance between traffic demand and capacity during incident-induced freeway congestion within a freeway corridor. Corridor traffic management imposes unique analysis requirements since it must consider collectively all routes within the freeway corridor impacted by the incident. Two key analysis requirements are: (1) estimating the incident effect, and (2) evaluating diversion opportunities and impacts.

Corridor traffic simulation models can be used to meet the analysis needs for corridor traffic management. They can estimate the incident effect based on the characteristics of the incident, traffic demand levels and patterns throughout the corridor, and the configuration of the corridor. Traffic management strategies during freeway incidents include providing information and adjusting traffic controls to facilitate desirable traffic diversion to alternative routes. Corridor traffic simulation models can be used to help answer such questions as when, where, and how much traffic to divert from the freeway to alternative routes in the corridor. With proper cautions, an experienced analyst can take full advantage of the simulation models when developing corridor traffic management strategies for freeway incidents.

This report presents a case study to provide an understanding of the the corridor analysis process, discuss the difficulties involved, and suggest the necessary precautions to take during analysis. In this case study, the Southwest Freeway (US 59) corridor in Houston was analyzed using the CORFLO model.

This report provides guidelines on the appropriate use of CORFLO, the corridor traffic simulation model whose capabilities most closely match the analysis needs for corridor traffic management, to answer these questions.

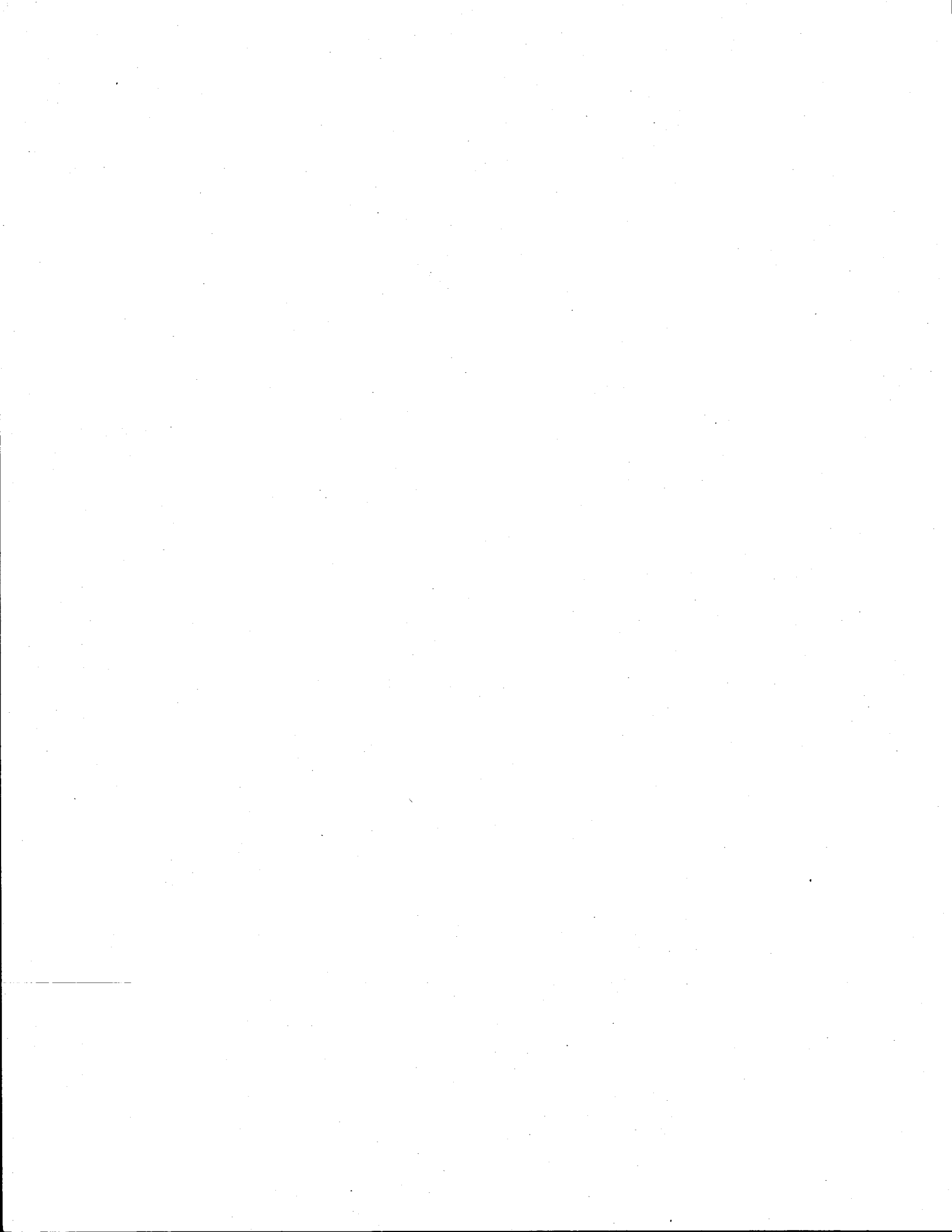


I. INTRODUCTION

The objective of corridor traffic management during freeway incidents is to make the most effective use of available corridor capacity to minimize the adverse traffic impacts of the incident. Key management questions include when, where, and how much traffic can and should be diverted from the freeway to alternative routes. Answering these questions requires an assessment of the potential impacts of the incident; an evaluation of traffic management alternatives; and the identification, selection, and implementation of the preferred alternative. This report provides guidelines on the use of CORFLO, a corridor traffic simulation model, to help answer some of these questions.

Although the quality and potential usefulness of traffic simulation models as decision support tools for corridor traffic management has increased, the application of simulation models continues to be limited. The objective of this report is to provide basic understanding of corridor traffic simulation models, and to suggest guidelines on how CORFLO can be best used to support decision making for traffic management during freeway incidents.

The main body of this report is divided into five chapters. Chapter 2 outlines the analysis requirements for the development of effective corridor traffic management strategies. Chapter 3 describes the basic features of corridor traffic simulation models, with emphasis on CORFLO. Chapter 4 provides guidance on using CORFLO to evaluate alternatives for corridor traffic management during freeway incidents. Chapter 5 presents a case study that illustrates the use of CORFLO. Chapter 6 concludes the report with recommendations.



II. ANALYSIS REQUIREMENTS

A freeway corridor is defined as a freeway and the system of roadways influenced by the freeway that serve travel demands between two or more geographical areas. A freeway corridor typically consists of a freeway, its frontage roads, the arterial streets that serve as alternative routes to the freeway and whose traffic conditions are affected by conditions on the freeway, and the cross streets that carry traffic between the freeway and those arterial streets. Figure 1 is a schematic of a typical freeway corridor.

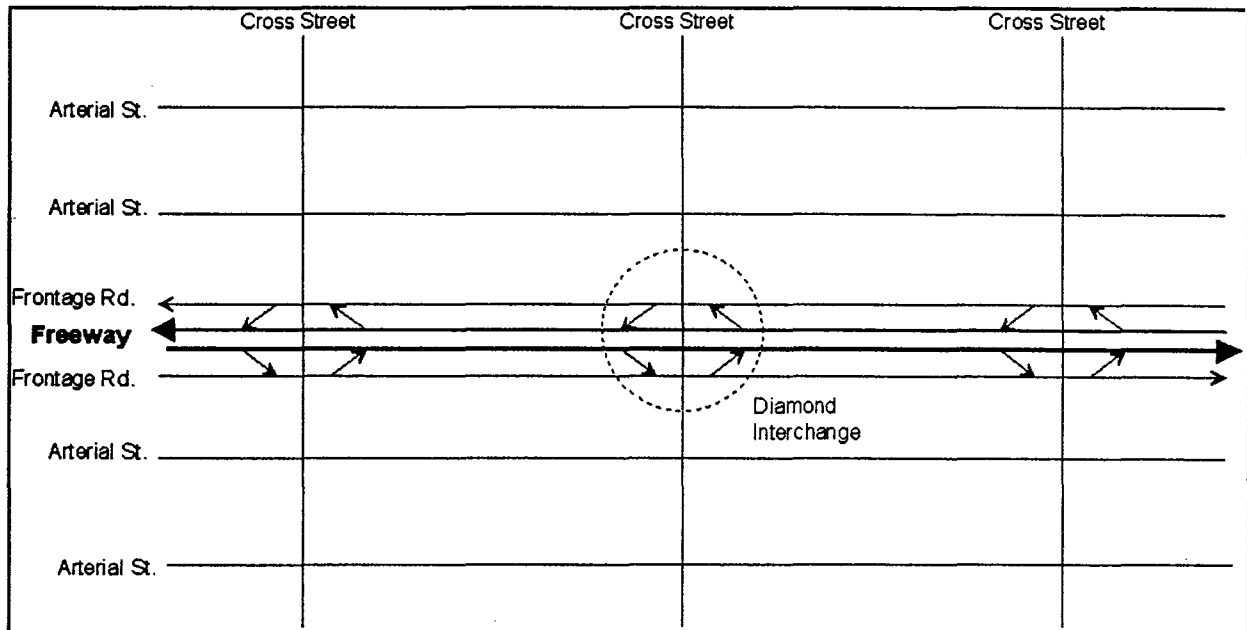


Figure 1. A Typical Freeway Corridor

Corridor traffic management imposes unique analysis requirements since it deals not with an individual freeway or arterial street, but with a system of interrelated freeway, frontage road, and arterial street routes. This chapter outlines the analysis requirements for developing strategies for corridor traffic management during freeway incidents. First, the analyst must determine the corridor-wide traffic impacts of an incident. If the impacts are sufficiently severe,

then the analyst should identify opportunities for traffic diversion to reduce the impacts and evaluate their corridor-wide benefits.

CORRIDOR-WIDE TRAFFIC IMPACTS OF INCIDENT

The traffic impacts of an incident must be predicted in order to identify both potential problem areas and potentially beneficial information and control actions. The scope of analysis should include not only the freeway but also the frontage roads and affected arterial streets.

The magnitude and location of traffic impacts of a freeway incident depend upon three primary factors:

- The characteristics of the incident,
- Traffic demand levels and patterns throughout the corridor, and
- The configuration of the corridor.

Important incident characteristics, with respect to their traffic impacts throughout the affected freeway corridor, include severity (i.e., whether the incident permits traffic to pass by the incident scene, the number of freeway lanes blocked, and the duration of the incident), time of occurrence (i.e., peak versus off-peak hours), and location of occurrence. These characteristics influence the traffic-handling capacity around the incident and the traffic demand levels and patterns that must be served in the corridor.

The traffic demand approaching the incident location and the demand levels and patterns throughout the corridor significantly affect both the magnitude and location of incident-induced delays as well as the availability of unused capacity on alternative routes for traffic diversion. In a particular corridor, demand levels and patterns are influenced primarily by the time of day. Therefore, both the magnitude of likely problems and range of potential traffic management strategies will vary depending upon when the incident occurs.

The configuration of a corridor is characterized by the capacity of the links and nodes (including at-grade intersections and ramp junctions) as well as the orientation of and connections between the freeway and arterial street system. The capacity of links and nodes is influenced by the number of lanes, geometry of the roadway, and control parameters. The corridor configuration influences the availability and attractiveness of alternative routes.

These three factors determine the magnitude and spatial distribution of traffic-handling capacity and traffic demand in the corridor. Corridor traffic simulation models have the

capability of analyzing the relationship between capacity and demand and estimating the resulting traffic conditions.

DEVELOPMENT OF DIVERSION STRATEGIES

"The most advanced corridor traffic control methods are based on determining the control that results in the most desirable traffic assignment in a network" (1). Freeway corridor traffic management strategies aim to improve freeway flow by diverting drivers away from congested freeways to alternative routes with unused capacity and, consequently, to minimize corridor-wide congestion levels.

Developing and evaluating strategies for traffic diversion during freeway incidents are complex tasks, since they require the analysis of traffic with various origins and destinations in dynamically changing corridor traffic conditions. A diversion strategy targets when, where, and how much traffic should be diverted from the freeway to alternative routes in the corridor, as well as the information and control actions for achieving those goals.

When evaluating diversion strategies, the critical issue is the tradeoff between the benefits of reducing congestion on the freeway and the impacts of additional traffic elsewhere in the corridor. The desired output from the evaluation is the optimal amount of traffic diversion for the given incident characteristics, traffic demand levels and patterns, and corridor configuration. The optimal would yield the lowest level of corridor-wide congestion measured in terms of total delay or travel time in the corridor. Generally, the optimal amount of diversion takes advantage of, but does not exceed, the unused capacity on alternative routes in the corridor. A control variable that has a major influence on the optimal amount of diversion is the signal timing on alternative routes. Well-coordinated signal timing can accommodate more diverted traffic with marginal delay increase—and therefore produce better corridor-wide performance—than uncoordinated signal timing. A question naturally arising is how much traffic diversion and what signal timing schemes would be most effective for a given diversion route in achieving the best network performance while keeping additional delay for other traffic movements within a tolerable limit.

Corridor traffic simulation models can be used to identify opportunities for diversion (i.e., the availability of unused capacity on alternative routes to the freeway), to estimate the

traffic impacts of different levels of diversion, and to evaluate the diversion strategies that yield the greatest benefits. This information must be combined with an assessment of drivers' likely route choice behavior under alternative information and control scenarios in order to select the information and control actions that are most likely to achieve the desired diversion levels and patterns.

III. CORRIDOR TRAFFIC SIMULATION MODELS

This chapter provides a brief introduction to corridor traffic simulation models and then a more detailed description of one particular model, CORFLO, whose capabilities most closely match the requirements for developing and evaluating strategies for corridor traffic management during freeway incidents.

INTRODUCTION TO CORRIDOR TRAFFIC SIMULATION MODELS

Chapter 8, "Traffic Operations Analysis," of the *Texas Highway Operations Manual (2)* describes and compares available computer programs that perform either freeway traffic simulation (HCS, FREQ, FREFLO, INTRAS, FRESIM, and QUEWZ) or signalized intersection/arterial street traffic simulation (PASSER II, PASSER III, TEXAS, TRANSYT-7F, and NETSIM). Corridor traffic simulation models have most of the same characteristics as these programs as well as two additional capabilities that make them uniquely appropriate for evaluating alternative strategies for corridor traffic management during freeway incidents.

The first important additional capability is that corridor traffic simulation models can represent both freeways and signalized arterial streets in an integrated network and simulate the movement of traffic on and between those facilities, whereas the other programs can simulate traffic on only one type of facility (either freeways or signalized intersections/arterial streets). The integrated modeling of both freeways and arterial streets by corridor simulation models is necessary to estimate the corridor-wide effects of incidents and to evaluate strategies for diverting traffic from a freeway to alternative routes in the corridor.

The second important additional feature of corridor traffic simulation models is that they can perform traffic assignment. This capability enables the identification of the most efficient distribution of traffic among the routes in a corridor. Traffic assignment takes as input an origin-destination trip table for the time period of interest, which indicates the number of trips between each pair of origins and destinations. The outputs are the traffic volumes on each link in the network, representing the most efficient distribution of traffic among the routes in the corridor. Typically in corridor traffic simulation models, trips are assigned to routes according to the user equilibrium criterion, which is the condition that no trip's travel time could be reduced by reassigning it to a different route. Thus,

the traffic assignment results represent a standard against which alternative corridor traffic management strategies can be judged.

The inputs to a corridor traffic simulation model include the corridor configuration, traffic demand levels and patterns, and incident characteristics. The corridor configuration is represented as a network of links whose length, number of lanes, and normal per-lane capacity are specified. Traffic demand levels and patterns are specified in the origin-destination trip table. Incident characteristics are described by the link on which the incident occurs, the number of lanes blocked (or reduction in capacity), and the time of occurrence and duration of the incident.

The outputs from a corridor traffic simulation model include both link-specific and corridor-wide measures of effectiveness. Link-specific measures include link speed, travel time, and delay. Corridor-wide measures include total vehicle-hours and vehicle-miles of travel, overall average speed, and total fuel consumption.

Corridor traffic simulation models can be used to estimate the traffic impacts of an incident with specified characteristics. Analysts can compare simulation runs modeling normal (i.e., non-incident) versus incident conditions to estimate the magnitude and spatial distribution of the impacts of an incident. These comparisons help identify potential problem areas as well as diversion strategies and supporting controls for mitigating those problems. The corridor-wide measures can be used to estimate the additional vehicle-hours and vehicle-miles of travel resulting from an incident and to compare the corridor-wide effectiveness of alternative traffic management strategies.

Corridor traffic simulation models can be used both to identify opportunities for diversion and to develop and evaluate alternative diversion strategies. The simulation model for normal conditions can be evaluated to identify unused capacity on alternative routes that is available for traffic diverting from the freeway. Alternatives for when, where, and how much traffic to divert from the freeway to alternative routes can be coded into the model and evaluated. Signal timing and ramp metering plans can be developed based upon these volumes, coded into the model, and evaluated. As a basis for comparison, the traffic assignment capability can be used to identify the most efficient distribution of traffic during an incident. Comparisons of simulation model outputs representing different diversion strategies can be used to compare the improvements in traffic conditions on individual links and corridor wide.

CORFLO

Several corridor traffic simulation models exist and considerable effort is underway to develop or adapt models to evaluate advanced traffic management system and advanced traveler information system alternatives. Among the currently operational models, CORFLO's capabilities most closely match the requirements for developing and evaluating strategies for corridor traffic management during freeway incidents. This section outlines the general features of CORFLO, reviews applications of CORFLO for corridor traffic management, and provides an evaluation of its performance.

General Features

CORFLO is a subset of the TRAF system developed by the Federal Highway Administration as a tool for evaluating transportation management strategies (3). TRAF is a software system, programmed in FORTRAN, which consists of component models that interface with one another to form an integrated system. The component models include microscopic and macroscopic simulation models for two-lane highways, arterial streets, and freeways. TRAF also has an equilibrium traffic assignment model.

CORFLO includes three submodels:

- FREFLO, a macroscopic freeway simulation model,
- NETFLO, a macroscopic arterial street simulation model, and
- TRAFFIC, an equilibrium traffic assignment model.

CORFLO can explicitly simulate freeways and surface streets in a single environment (3). Each submodel is applied to a portion of the entire network, known as a subnetwork. Each subnetwork is simulated by a single CORFLO submodel. This interfacing of adjoining subnetworks is accomplished by defining interface nodes, which are the points at which vehicles leave one subnetwork and enter another. Associated with each interface node is a vehicle holding area. A vehicle exiting a subnetwork via an exit interface link is stored in the vehicle holding area until it can be moved by the simulation model processing traffic on the adjoining subnetwork. Continuity of flow from one subnetwork to the next is preserved by model logic. Since the representation of the traffic stream may differ among submodels, it is necessary for the logic to represent the traffic stream in a common format. Specifically, the traffic stream entering an interface node is always disaggregated

into individual vehicles, regardless of its subnetwork-specific representation. This disaggregated traffic representation is then transformed into the adjoining subnetwork-specific traffic representation just downstream of the interface node.

Use of CORFLO for Evaluating Corridor Traffic Management Strategies

CORFLO has the capability of evaluating roadway performance during freeway incidents and determining network links that are overloaded or under-utilized within a corridor in terms of various corridor-wide measures. CORFLO helps answer several questions that arise in developing and evaluating corridor traffic management strategies for incident conditions, including: (1) how much traffic should be diverted from the freeway in response to a capacity-reducing incident, (2) to which alternative routes that traffic should be diverted, (3) when (relative to the time of incident occurrence) the traffic should be diverted, (4) how long the incident will affect system performance for a given demand level, and (5) by how much various traffic management strategies could reduce incident-induced delay.

CORFLO can analyze alternative diversion strategies (each having different diversion percentages, locations of diversion, and alternative routes) for various incident scenarios (each differing with respect to the time and location at which the incident occurs, and the duration and severity of the incident). Comparing CORFLO outputs for the alternative diversion strategies can help identify the most desirable distribution of traffic among available routes in a corridor for a particular incident scenario. Then, these distributions can be used to develop ramp metering rates and signal timing plans for each incident scenario. Chapter 5 of this report presents a case study that illustrates some of these analyses.

Evaluation of CORFLO

This section reports an evaluation of CORFLO's capabilities and effectiveness for evaluating alternative strategies for corridor traffic management during freeway incidents. The evaluation indicates that although CORFLO is an appropriate tool for this application, it has several weaknesses that affect the reasonableness of its results and, therefore, its effectiveness as an evaluation tool in corridor traffic management (4). Users must consider these weaknesses when applying CORFLO.

The evaluation included a test of CORFLO's capability to handle peak-period traffic conditions (4). The test showed that the FREFLO entry links at the upstream ends of the modeled network exhibited unreasonably large delay under peak-period conditions. The entry links store all vehicles and discharge these vehicles into the network as conditions on the downstream links permit. For small networks, the incident effect during the congested period can quickly propagate to the upstream end of the network. Consequently, the link immediately downstream of the entry link allows only a few vehicles to be discharged from the entry link since the link is already congested. The entry link must hold all of the demand to be served, regardless of its storage capacity, because FREFLO has no mechanism to meter the traffic entering the network; whereas, in reality, the excess demand would be stored outside the network. In this case, the statistics for the entry links are not valid and should not be included in the subnetwork total statistics. (The FREFLO submodel does not explicitly provide statistics for individual entry links, but includes them in the subnetwork total). Even if the storage capacity of the entry link is not exceeded, the entry link should exhibit free-flow conditions throughout the simulation period to ensure that the incident effect is confined within the network. The network must be large enough to satisfy this condition.

The evaluation of CORFLO's peak-period modeling capabilities also revealed a problem of queue spillback at many arterial street links in the NETFLO submodel (4). This problem would bias the simulation results, because delay estimates for some of these spillback links were unreasonably large. Under off-peak conditions, the spillback problem was observed at only a few links, and delay estimates for these links were small enough not to bias the overall result.

One of the inherent weaknesses of the CORFLO model is that the traffic assignment algorithm does not have the capability to account for time-varying flow rates and changing turning movement patterns (5). The basic assumption of CORFLO's traffic assignment technique is that drivers have full information about the whole network, and they avoid congested portions of the network based on that information. However, in reality drivers do not have enough information concerning network-wide traffic conditions when incidents of short duration occur on the freeway. Many drivers probably arrive at the incident link if it is part of their normal route, and then they make another decision about whether or not to divert to an alternative route. When an incident occurs, traffic conditions change during a simulation period; however, CORFLO assigns traffic based on the initial condition specified in the input files, and this flow pattern is maintained throughout the whole simulation period. If an

incident is specified as the initial condition, the CORFLO assigns less traffic on the affected links than the normal traffic volume on those links because the capacity is reduced due to the incident. In this case, CORFLO is simulating the situation that drivers have information about the incident and avoid the locations affected by the incident. This weakness can be overcome by placing the normal condition before the incident in the simulation period. CORFLO will then assign normal traffic volumes on all network links. However, CORFLO cannot simulate in-route diversion caused by delays near the incident link. This limitation cannot be overcome within the existing CORFLO model; new assignment techniques would need to be developed to overcome this problem.

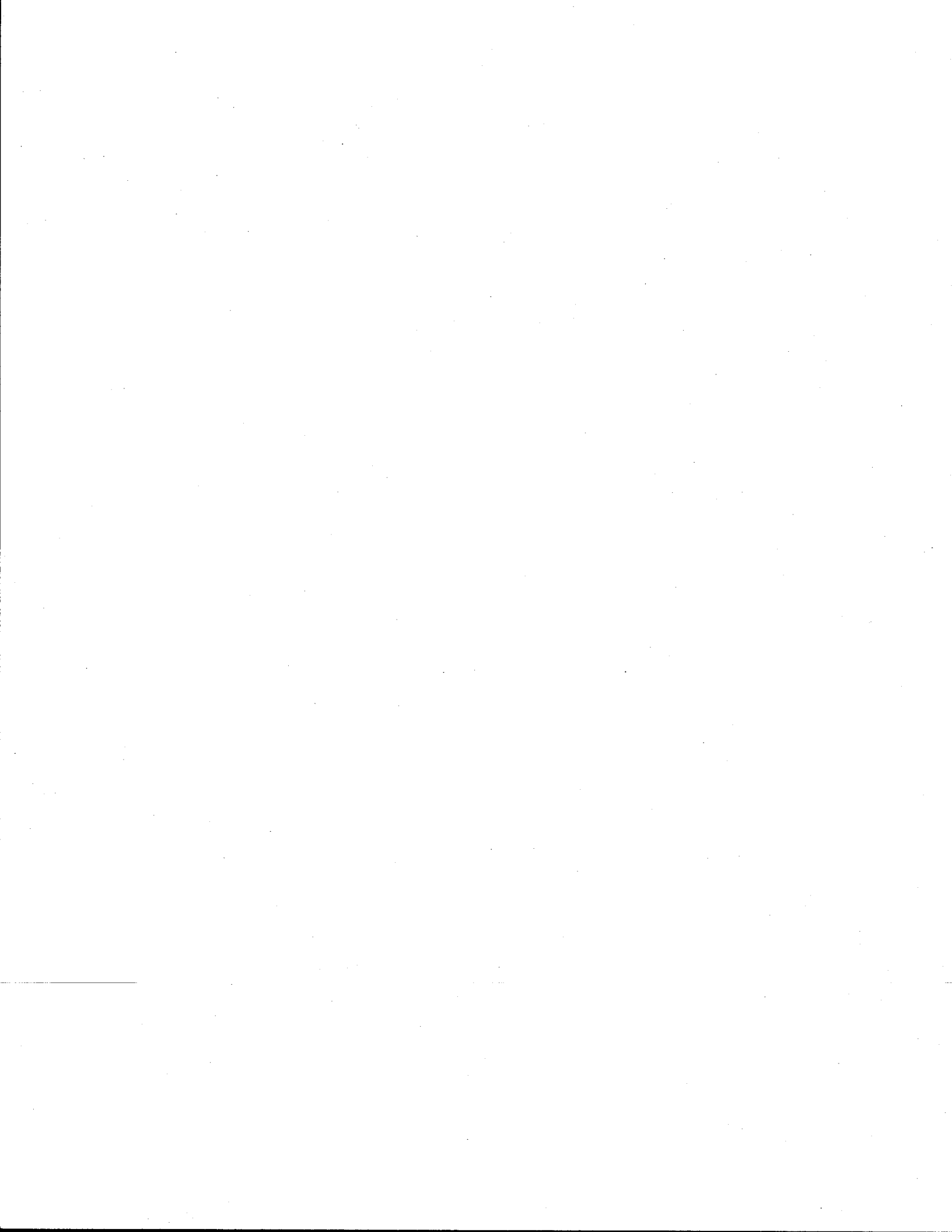
CORFLO does not have utilities to conveniently examine alternative diversion strategies. Simulation of the diversion strategies using the CORFLO model involves manual jobs to control the volume of diverting traffic. Network traffic volumes can be provided in two ways. One method is to utilize TRAFFIC in conjunction with the simulation submodels by inputting the origin-destination trip table. The other method is to specify link volumes and turning percentages. Even though the latter method does not require the use of the assignment model, the assignment results from TRAFFIC should be used when ground-count data are not available. When a diversion strategy is simulated, the origin-destination trip table cannot be directly used as a part of the data for a simulation run since CORFLO does not allow any control over the trip table to specify the diverting traffic. The latter method should be utilized along with the volumes and the turning movement patterns obtained by the TRAFFIC model, and then modifications must be made to these volumes and turning movement patterns to specify the diverting traffic. This procedure is cumbersome and involves two separate computer runs—assignment with TRAFFIC only, and simulation by the FREFLO and NETFLO submodels with the modified assignment results from TRAFFIC.

Another weakness becomes apparent when diversion occurs at freeway exit ramps. CORFLO represents these ramps as interface links between freeway and arterial streets. These links are expected to be somewhat congested when diversion is implemented. However, CORFLO is incapable of dealing with queuing effect on these interface links, which may cause a problem in evaluating diversion strategies.

CORFLO does not have the capability to handle various signal timing plans corresponding to time-varying traffic conditions. CORFLO allows only one signal timing plan as a basic input for the entire simulation period.

SUMMARY

In general, CORFLO is an appropriate tool for evaluating alternative corridor traffic management strategies for freeway incidents. It can model incidents and estimate their traffic impacts throughout a freeway corridor. CORFLO has several weaknesses, however, that users must recognize and consider when evaluating model results.



IV. CORRIDOR ANALYSIS GUIDELINES

This chapter presents general guidelines on using CORFLO to evaluate corridor traffic management strategies for freeway incidents. First, it describes the basic steps in CORFLO-based corridor analysis. Next, data requirements to build a CORFLO model of a corridor are identified. Then, guidance is provided on the interpretation of CORFLO results. Finally, keys to the accuracy and reliability of the model are discussed.

STEPS IN CORFLO-BASED CORRIDOR ANALYSIS

The basic steps in using CORFLO to evaluate the corridor-wide impacts of alternative corridor traffic management strategies include the following:

- Define the study area. The study area would generally include a single freeway corridor. The freeway segment should have logical limits (e.g., major interchanges with other freeways, limits of the urban area, downtown). In addition to the freeway, the corridor would include the frontage roads; those arterial street parallel to the freeway that are logical alternative routes; and the cross streets that connect the freeway, frontage roads, and parallel arterial streets. The study area should be sufficient to contain the effects of the incidents and traffic management strategies that are studied.
- Select the links to be modeled. The study area must be translated into a network that is sufficiently detailed, with respect to the number of links modeled, to be able to perform the desired evaluations with sufficient accuracy. In general, the links in the network should cover the paths pursued by the vast majority of trips, including:
 - All freeways in the study area,
 - All interchanges and ramps,
 - All major arterial streets paralleling and crossing the freeway corridor,
 - All signalized intersections along the major arterial streets,
 - Minor arterials and collectors that are continuous through the corridor, and
 - Collectors and local streets that connect major traffic generators with other modeled links.

- Collect the required input data. The input data that CORFLO requires to model a corridor must be identified and collected. The next section describes CORFLO's data requirements in more detail.
- Code and debug the network. The network structure and required data are coded numerically in the format specified by CORFLO. Users must perform preliminary runs of the model to identify and correct any coding errors.
- Calibrate the model. Model calibration involves: (1) network calibration, and (2) calibration of assigned link flows. The model should be calibrated to ensure that the network behaves realistically and as intended in terms of selected measures, and the assignment model reasonably reproduces actual traffic volumes. A more detailed discussion of model calibration is provided later in this chapter.
- Develop a set of analysis scenarios. Scenarios should incorporate the incident characteristics, diversion strategies, and control strategies (i.e., signal timing and ramp metering plans) to be evaluated using the model. A scenario is a unique combination of the above factors. A set of scenarios should be developed so that the simulation results provide meaningful comparisons of alternative strategies.
- Perform analysis. CORFLO must be run once for each scenario. The model results are then analyzed to provide comparative evaluations of alternative strategies.

DATA REQUIREMENTS

CORFLO requires three types of data:

- Network data. These data include the number of lanes, section lengths, on-ramp and off-ramp locations, nominal section capacities, and the network of intersections and streets.
- Traffic data. The model requires the densities and speeds for the initial state, upstream freeway volume and on-ramp rates for input volumes, and signal timing data on the arterial streets. Model calibration requires ground count volumes.
- Trip table. The trip table is a matrix of the number of trips during the simulation period between each origin-destination pair. The origins and destinations represent those points where aggregations of traffic enter and leave the modeled network. The assignment process requires the trip table to load the network with vehicles.

Most of the required data should be readily available in the files of state and local transportation agencies. The district offices of the Texas Department of Transportation are the best source for most of the network data for freeways, ramps, and frontage roads. Most intersection geometry, signal timing data, and intersection volumes data are available from the city transportation agency. Link lengths (e.g., the distance between intersections) can be obtained from maps or the link data maintained by the metropolitan planning organization for the regional planning model.

The trip table for the study area for the desired time of the day can be extracted from the 24-hour trip table prepared for the regional planning model. Since the network typically represents a single corridor, which is substantially smaller than the regional planning model for which the original trip table is prepared, it is necessary to extract the new trip table just for the study corridor from the original trip table. This process is referred to as "windowing." Most regional planning models can perform the windowing process.

If any of the required network or traffic data are not available, then field data collection must be conducted. The field data collection does not usually take major effort since most of the data can be obtained in readily available forms. The data collection may involve sketching intersection geometry, measuring link distances, and counting traffic volumes.

INTERPRETATION OF CORFLO RESULTS

CORFLO output should not be considered the final product of a corridor analysis. The results are like raw data that users must interpret properly. The following guidance is provided for accurate and effective interpretation of simulation results.

General Rules

The following are general rules for proper interpretation of CORFLO results:

- Use CORFLO results for relative comparisons. Do not assume that the absolute values of the various measures reported in the output are completely accurate.
- Establish normal traffic conditions with no incident as the base condition against which the subsequent results can be compared. Normal network traffic conditions should be thoroughly evaluated to be sure that the model is well-calibrated.

- Ensure that all incident effects are contained within the network. In other words, the network boundary links should exhibit normal conditions at all times. If queuing extends beyond the network boundary, then that portion of the queue outside the network is ignored and the incident effects would be underestimated.
- Ensure that the temporal effects of the incident are kept within the total simulation period. Network traffic conditions must return to normal by the end of simulation. Again, the incident effects would be underestimated if incident-induced congestion continues beyond the end of the simulation period.
- Examine the assignment results to ensure that the network size does not affect the demand pattern. For small networks, some demand near the network boundary that would otherwise detour away from the network is forced to enter the network due to the limited route choices. The analyst should check the reasonableness of the routes assigned traffic between selected origin-destination pairs.
- Exercise caution when analyzing a small network, because network-wide estimates for a small network are sensitive to any unreasonable results for one or more influential links. For instance, when a unreasonably large delay (that is, large enough to constitute a large portion of the total delay) occurs on a particular link, the total delay estimate is biased since it does not properly represent the overall network-wide conditions.
- Do not directly apply the results for one corridor to other corridors because corridor configurations and traffic pattern are site-specific. Separately model and evaluate each corridor.

Impact of Incidents

The following guidance pertains to the interpretation of CORFLO results for assessing incident effects:

- Estimate the overall incident effect by comparing the difference in magnitude of network-wide measures from CORFLO runs for a given incident scenario versus the run representing normal conditions.

- Examine link-specific measures from CORFLO runs for a given incident scenario to identify links with significant changes in measures compared to the normal condition. These links represent the locations that are most impacted by the incident.
- Conduct a series of CORFLO runs with various incident scenarios, and compare the results in order to estimate the quantitative/qualitative relationships between the characteristics of incidents and their effect on network conditions.
- Observe traffic conditions on links near the incident link for queue buildup/dissipation patterns for each time slice. This observation would be useful to investigate how the incident affects downstream ramp conditions and how congestion propagates to the frontage roads and arterial streets.

Diversion Strategies

Guidance on using CORFLO to assess alternative diversion strategies includes the following:

- Analyze the CORFLO results for the normal conditions to identify potential diversion routes and to estimate unused capacity on those routes.
- Examine the minimum path trees reported by the traffic assignment model to identify the major origin-destination pairs that would use the incident link under the normal condition. Generally, these are the most logical origin-destination pairs to target for diversion.
- Estimate the overall effectiveness of a diversion strategy in terms of delay savings by subtracting the CORFLO-estimated delay for a given incident/diversion scenario from the delay for the incident/no diversion scenario.
- Conduct a series of simulation runs using various amounts of diversion and compare the results. A plot of the total network delay versus the volume of traffic diverted from the freeway to the specified diversion route(s) can be used to estimate the optimal volume of diverting traffic for a given traffic management strategy (i.e., fixed diversion route(s) and control schemes).
- Compare diversion strategies with existing and optimized signal timing plans for the diversion routes to evaluate the benefits of signal optimization in accommodating the diverted traffic.

FACTORS AFFECTING THE RELIABILITY OF SIMULATION RESULTS

In general, the accuracy and reliability of a traffic simulation model depends upon the quality of input data, the level of detail in the network structure, and calibration.

Quality of Input Data

Accurate input data are required to obtain good results. Data may be obtained either from existing sources or by conducting original data collection. Collecting original data would generally yield the most reliable data. In most cases, however, the large data collection effort that would be required would not be practical due to cost and time constraints.

When using existing sources of data, care must be taken to ensure the data are the most current available and/or are updated to the extent that they would not bias the model. Also, to the maximum extent possible, the data from different sources should be compatible in terms of date and level of detail.

Level of Network Detail

The levels of effort and model run time, which increase as the level of network detail increases, are practical constraints on the number of links that can be represented in the modeled network. Generally, the network for CORFLO will be at least as detailed as the representation of the corridor in a regional planning model. The network will typically include all freeways, frontage roads, and arterials, and most collectors. Local streets are generally excluded, unless they provide access to major traffic generators.

One set of criteria for the level of network detail is as follows (6):

- The network should be representative of the true roadway capacity within the corridor.
- Collectors and local streets should be modeled with sufficient density to prevent the effect of point loadings from appearing on primary routes.
- The network should be sufficiently dense that trips will not be forced unreasonably onto primary links in a particular area and in a particular direction.
- The network should be sufficiently dense to represent the paths taken by a large majority of trips.

Model Calibration

Model calibration is an essential part of the modeling procedure since the accuracy of analysis results heavily depends upon whether or not the model is properly calibrated. Calibration improves the accuracy of assignment and simulation results with various incident scenarios and diversion strategies and, in turn, the credibility of the analysis and evaluation results.

Model calibration is performed using ground count volume, speed, and travel time data. Calibration may be performed by adjusting model parameters and input data. In most cases, however, adjustments are made only to the input data since the default values for most model parameters have been pre-calibrated for the most common conditions and the model's accuracy is more sensitive to the input data than to model parameters.

Network Calibration

The characteristics of each link as coded should be checked to ensure that they are properly represented and coded accordingly in the input file. Minimum path trees as reported by the assignment model should be checked to ensure that they are logical and realistic. The model estimates of speed/travel time on selected links should be compared with the observed average speed/travel time for a given time period of the day to ensure that the difference falls within a reasonable range.

Calibration of Assigned Link Volumes

Assigned link volumes should be compared against the ground count volumes on the selected links. Assignment accuracy can be evaluated using both macro-level and micro-level measures. Chang and Dresser (7) provide a detailed description of macro and micro-level evaluation methods.

Macro-level measurements of assignment accuracy are those measures that analyze the entire network or specific portions of the network. Such measures include volume counts (on screenline, cutline, selected links, and travel routes) and vehicle-miles of travel. These macro-level measures are evaluated statistically using a hypothesis testing method such as the small-sample Wilcoxon signed-rank test.

Assignment accuracy can also be evaluated using micro-level measures. Micro-level measurements of assignment accuracy are those measures that analyze the differences between counted and assigned volumes on a link-by-link basis. The evaluation of link differences employs common statistical measures and nonparametric statistical tests. Micro-level measures include: (1) distribution of link difference by error ranges; (2) statistical measures of link differences such as the mean difference, root-mean-square-error, and standard deviation; and (3) statistical tests of link differences such as Chi-Square, Kruskal-Wallis, and the large-sample Wilcoxon signed-rank tests.

No assignment procedure will exactly replicate observed ground count volumes. Possible sources of variation include measurement errors in the ground count volumes, network configuration, accuracy of the trip table, and the assignment procedure itself. The network configuration should be checked to ensure that the network links, especially those links with relatively large variations, are properly represented and coded accordingly. For proper comparison of the assigned volumes and the observed ground counts, the trip table and the ground counts should be based on the same base year. The base year for the trip table should be the same as the base year for the network and traffic data.

Few techniques are available to remedy the link difference due to the trip table inaccuracy. All or part of the trip table may be adjusted when any consistent patterns of link differences are observed. For instance, when the assigned volumes on the cordon links (delineating the network boundary) are consistently greater or smaller than the actual observed ground counts, the trip table may be factored by the ratio of the modeled-to-observed cordon counts. A similar adjustment can be made for the origin-destination pairs that use a common section of a major facility based on the difference between the assigned volume and ground count on that section.

There are neither systematic calibration procedures nor universally accepted criteria that ensure the model accuracy. Although it is difficult to establish the desired level of accuracy for which all practitioners should strive, it is recommended that each analyst establish desirable accuracy levels relative to the intended use of the analysis results.

V. CASE STUDY

This chapter presents a case study to illustrate the use of CORFLO to evaluate corridor traffic management strategies for freeway incidents. First, it describes the study methodology. Then, it presents the case study results.

STUDY METHODOLOGY

The case study focuses on answering the following questions:

- How much traffic should be diverted from a freeway to alternative routes in response to a capacity-reducing incident?
- How much benefit can be gained by optimizing traffic signal timing on alternative routes used by traffic diverted from the freeway?
- How much can alternative diversion and signal control strategies reduce incident-induced delay throughout the corridor?

Since network geometry and traffic pattern are site-specific, the results of this case study network may not be directly applicable for other corridors. The analysis process and results, however, are typical of a CORFLO-based corridor analysis of traffic management alternatives for freeway incident.

The study was performed on the US-59 Southwest Freeway corridor in Houston, Texas. This network was analyzed using the CORFLO model. A set of scenarios was designed so that comparisons between simulation results from each scenario could be made. The scenarios were developed based upon off-peak period traffic. After the geometry data for the network were coded into a CORFLO input data file, signal timing plans and the off-peak period trip table for the network were added to the input data file. A freeway incident was then coded by specifying the incident location and the reduced capacity due to the incident. All data were coded into a single data file for each run. A set of CORFLO outputs was obtained from a series of simulation runs for various incident, diversion, and signal control alternatives. These outputs were used for all comparisons and analyses.

Study Area

The US-59 Southwest Freeway corridor study area includes a heavily-traveled, major urban freeway and multiple alternative arterial streets. The study area extends from the Houston central business district to near Beltway 8, and from Beechnut to Westheimer. The location of the study corridor is shown in Figure 2.

Simulation Model

CORFLO was used to model the study area. All three components of CORFLO (FREFLO, NETFLO Level 2, and TRAFFIC) were employed. FREFLO was used to model the freeway subnetwork. NETFLO Level 2 was used to model the frontage roads and arterial streets. TRAFFIC, a user equilibrium traffic assignment model that interfaces with the simulation models, was used to translate the input trip table into the link-specific turning volumes required by the simulation models.

Measure of Effectiveness

The measure selected to compare alternative strategies was the total corridor-wide delay (or travel times) in vehicle-hours. Each CORFLO simulation submodel (FREFLO and NETFLO Level 2) provides a delay estimate for the roadway facilities it represents. Corridor-wide totals are computed by combining the measures for each submodel.

FREFLO calculates link delay based on the difference between free flow speed and operating speed. In other words, delay is the difference in travel time between free flow conditions and actual conditions governed by the link volume.

In NETFLO Level 2, delay is composed of a uniform element, a random element, and the delay due to oversaturation. The uniform delay is calculated by averaging the queue length over the cycle. Delay also accrues due to the random arrivals of vehicle. The random and oversaturation delay is a function of degree of saturation. Also, several refinements have been introduced in the logic to account for the impact of start-up lost time, delay due to dispersion, delay experienced by turning vehicles, and truck traffic. Lieberman et al. (8) provide a detailed description of the algorithm for delay calculation.

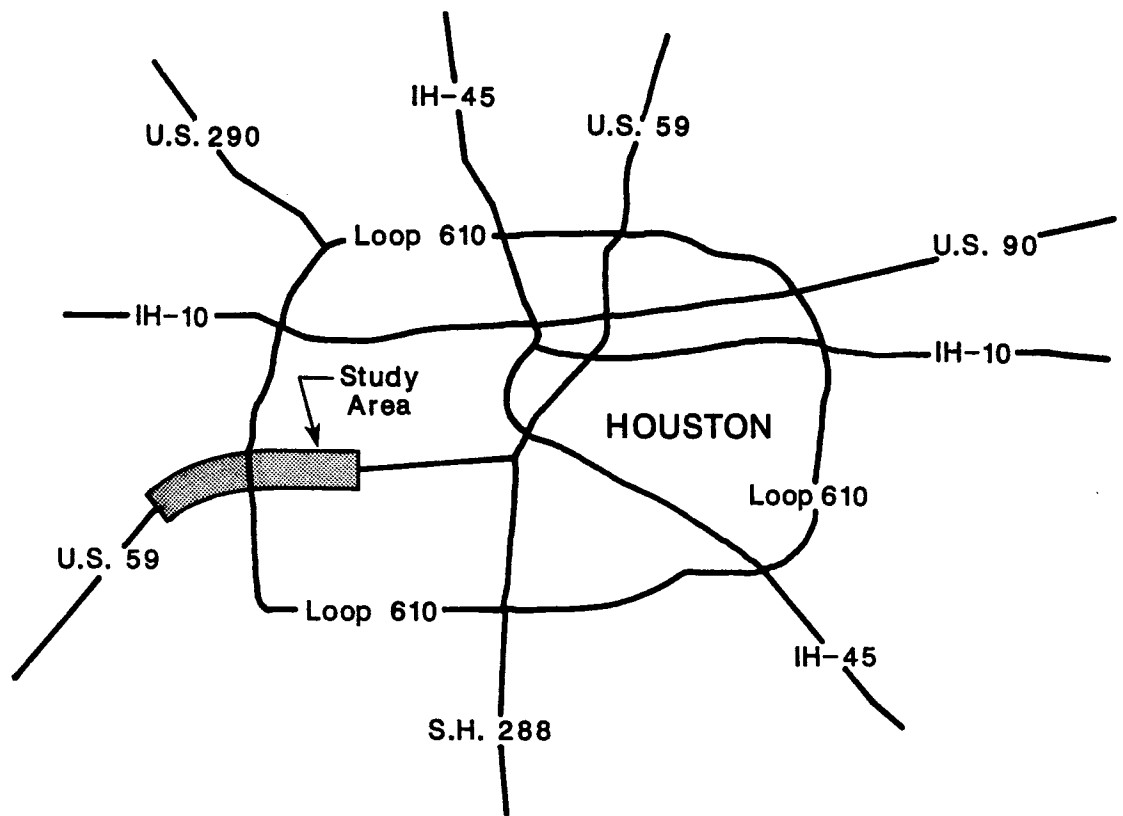


Figure 2. Location of the Study Corridor

Data Collection

CORFLO requires network and traffic data and a trip table, as described in Chapter 3. Most of the data were readily available from previous research conducted in the US-59 freeway corridor. The Texas Department of Transportation provided information on the general freeway configuration and ramps. Traffic volume data and signal timing information were obtained from the City of Houston. The off-peak period trip table was derived from the 24-hour trip table of the study network. The original 24-hour trip table was obtained from the regional planning model developed by the Houston-Galveston Area Council in 1990. The trip table was computed by factoring the percent of daily trips for the off-peak period to the total 24-hour trip table.

Network Building

The network-building task was conducted in two stages. In the first stage, a small network was constructed for analysis, since the small network can be conveniently analyzed with a relatively small calibration effort. The study site for this small network was a portion of the larger US-59 Southwest Freeway corridor network built in the second stage. The smaller network includes the freeway, eastbound and westbound frontage roads, and five cross streets. The site is located east of IH-610 and extends from Newcastle to Kirby Drive. The larger network is composed of a 19-km (12-mi) section of US-59, six major parallel arterials (Beechnut, Bissonet, Bellaire, Westpark, Richmond, and Westheimer), IH-610, and ten cross streets. Figure 3 depicts the study corridor. The study corridor was translated into a CORFLO network consisting of a number of nodes and links. Figures 4 and 5 illustrate the CORFLO network representation of the smaller and larger networks, respectively. The small network contains 87 nodes, 154 links, and 16 zones. The larger network contains 647 nodes, 1275 links, and 197 zones.

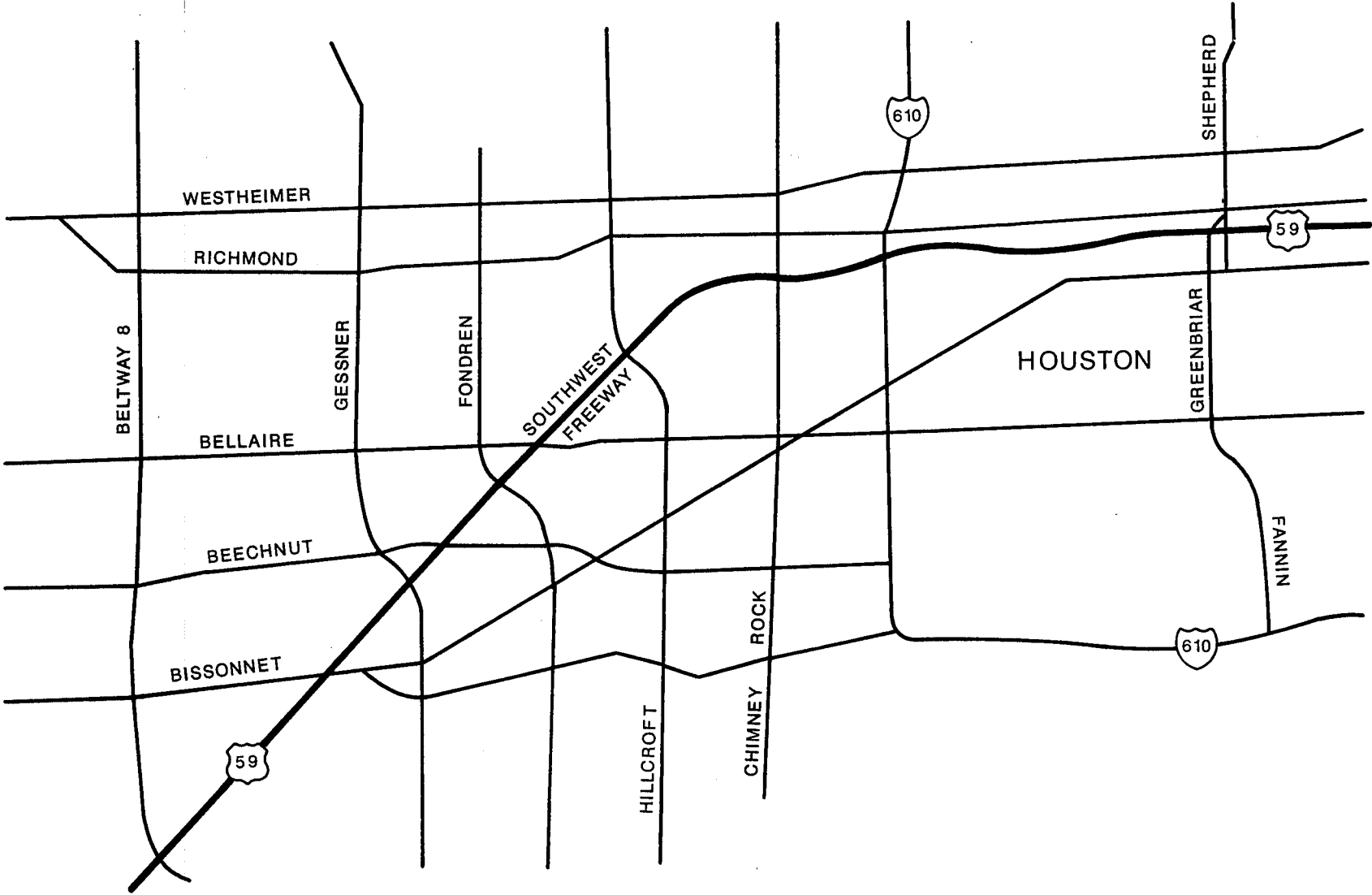


Figure 3. Southwest Freeway Study Corridor

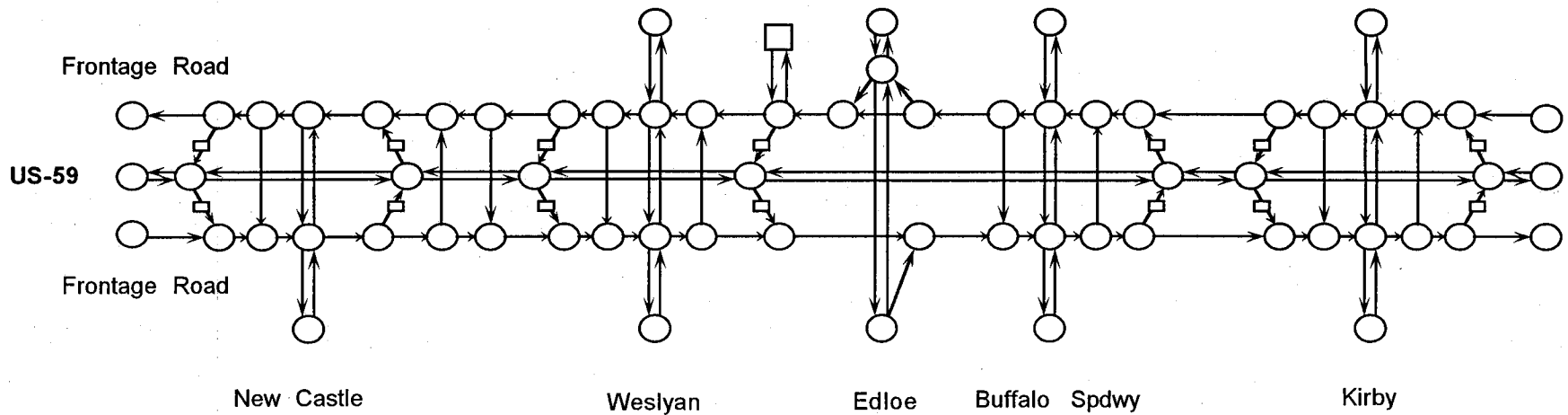


Figure 4. CORFLO Network Representation of the Small Corridor

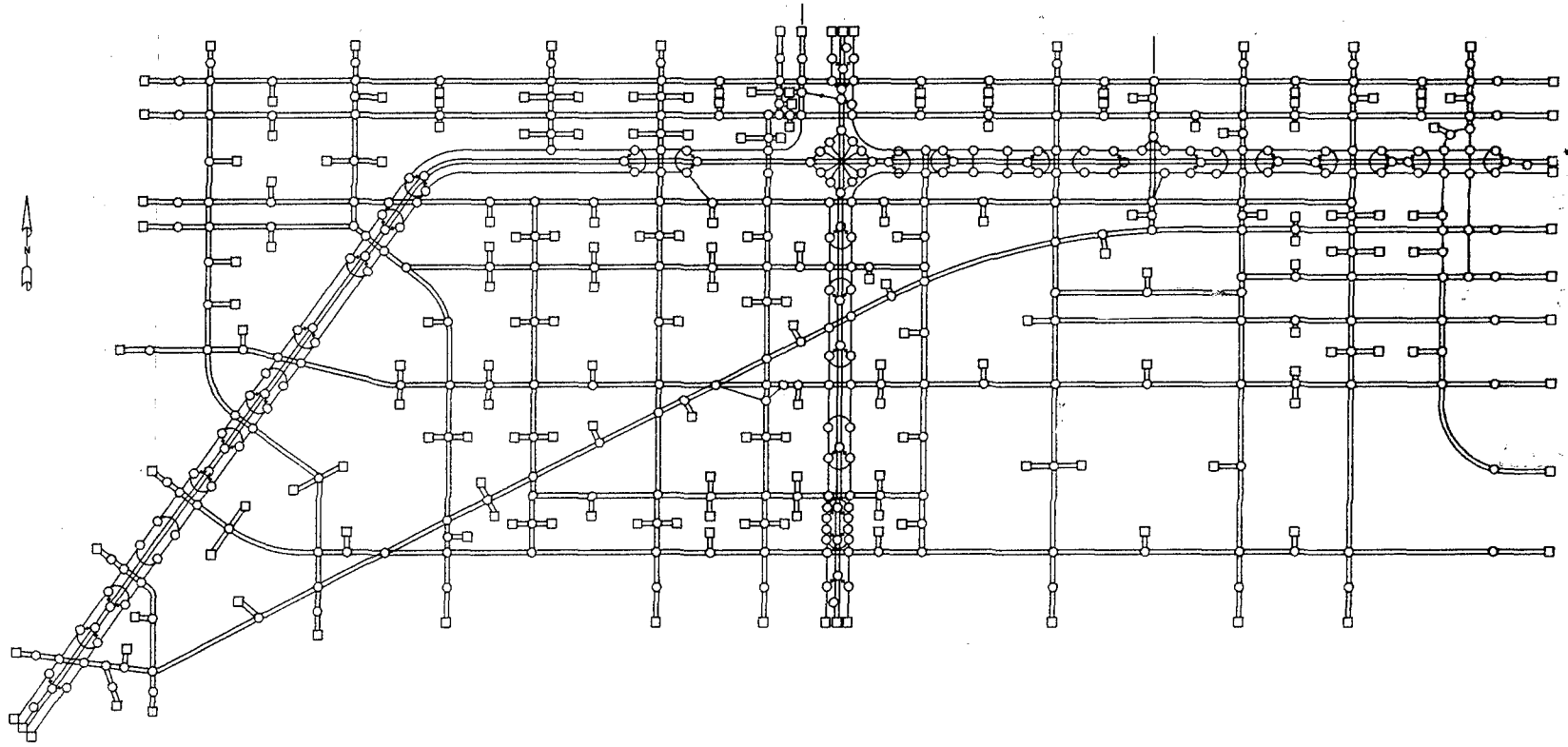


Figure 5. CORFLO Network Representation of the Large Corridor

ANALYSIS WITH THE SMALL NETWORK

Analysis Scenarios

The small network built in the first stage of the network-building task was used for analysis. A set of scenarios were developed so that the results of the simulation of each scenario could be effectively compared. These scenarios include:

- Scenario 1: off-peak period traffic, normal condition without incident;
- Scenario 2: off-peak period traffic, half-hour 1-lane-blocked incident with the same link volumes as the normal condition (no diversion);
- Scenario 3: off-peak period traffic, half-hour 2-lanes-blocked incident with the same link volumes as the normal condition (no diversion);
- Scenario 4: off-peak period traffic, half-hour 1-lane-blocked incident, a diversion strategy in effect with the existing frontage road signal timing plan;
- Scenario 5: off-peak period traffic, half-hour 1-lane-blocked incident, a diversion strategy in effect with a coordinated signal timing plan;
- Scenario 6: off-peak period traffic, half-hour 2-lanes-blocked incident, a diversion strategy in effect with the existing frontage road signal timing plan; and
- Scenario 7: off-peak period traffic, half-hour 2-lanes-blocked incident, a diversion strategy in effect with a coordinated signal timing plan.

Signal Optimization

The link-specific volumes were assigned during a preliminary CORFLO run. In this stage, only TRAFFIC was utilized. Signal timing was then optimized using PASSER III based on the assigned link volumes. Optimization was conducted for the diamond interchanges through which the diverted traffic travels. Each diversion percentage requires a separate PASSER III run for optimization because different traffic volumes on the frontage road would result in different optimized signal timings.

Simulation Runs

The total simulation period was 2 hours (from 9:30 to 11:30 A.M. Figure 6 shows the assumed incident location. This freeway section has 4 lanes in each direction. The incident occurs at 10:00 A.M. in the inbound direction and continues until 10:30 A.M. The capacity during the incidents was assumed to be 4,560 vph for the 1-lane-blocked incident, and 2,960 vph for the 2-lanes-blocked incident (9). Figure 6 also shows the assumed diversion route that includes 1 exit ramp, the frontage road, and 1 entrance ramp. The diverting traffic passed through two signalized intersections at Wesleyan and Buffalo Speedway. The diversion percentage is defined for simulation purposes as the percentage of the freeway through-traffic forced to exit at a desired ramp. Various diversion percentages were examined for scenarios 4, 5, 6, and 7. Diversion was simulated for 30 minutes during the same time period as the incident (10:00 - 10:30 A.M.) for all diversion percentages.

Methodology for Comparison and Evaluation

A number of comparisons and evaluations can be made with the results from the series of CORFLO simulation runs. Most of the evaluation efforts were directed toward estimating the diversion percentage-delay relationship for the network.

Possible comparisons and corresponding measures in question are as follows:

- Scenario 1 versus Scenarios 2/3: maximum delay due to the incident;
- Scenarios 4/6: optimal diversion percentage for the existing timing plan;
- Scenarios 5/7: optimal diversion percentage for the coordinated timing plan;
- Scenarios 2/3 versus Scenarios 4/6: delay savings due to diversion strategies with the existing signal timing;
- Scenarios 2/3 versus Scenarios 5/7: delay savings due to diversion strategies with the optimized signal timing;
- Scenarios 4/6 versus Scenarios 5/7: benefits from frontage road signal-coordination;
- and
- Scenario 1 versus Scenarios 4/6 and 5/7: efficiency of diversion strategies in terms of how close the incident condition was to the normal condition (no incident);

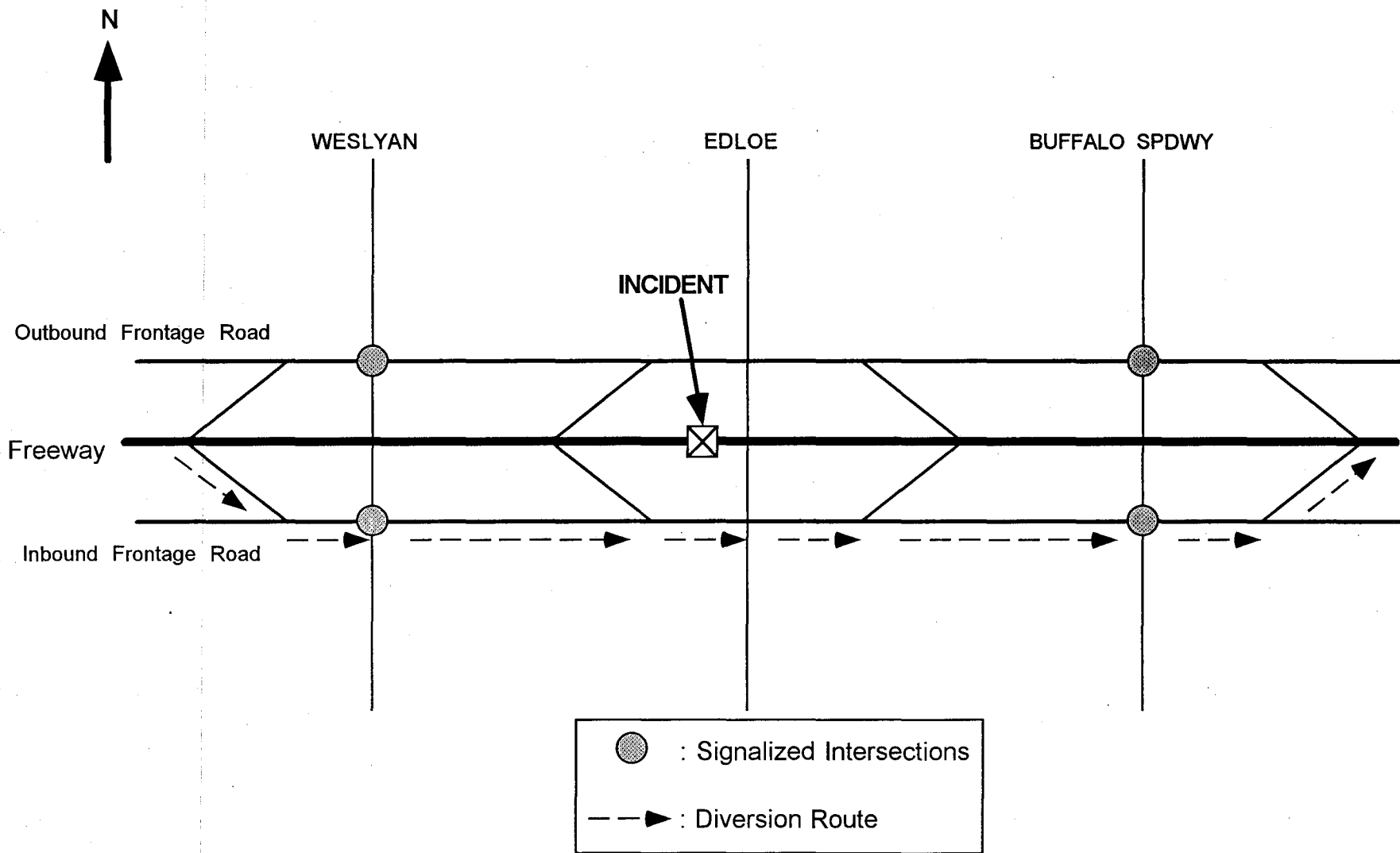


Figure 6. Schematic of the Incident Location and the Diversion Route

Results

Table 1 summarizes the results from the CORFLO runs for the various scenarios. This section discusses the comparisons enumerated above based upon these results.

Normal Traffic Conditions

The TRAFFIC submodel assigned the volumes to each link in the network based on normal conditions with no incident (scenario 1). In general, the network conditions are good with no major congestion areas.

The average volume-to-capacity ratio (V/C) of the inbound freeway was 0.63, which corresponds to a level of service C. The freeway has a potential to experience severe congestion if the capacity is reduced by a lane-blocking incident. The demand at the assumed incident link was 4,914 vph, which is well below the capacity (8,000 vph), and thus normally can be served without queuing. However, the incident would reduce the capacity of the link from 8,000 vph to 4,560 (1 lane blocked) or 2,960 vph (2 lanes blocked). As a result, the demand would exceed the capacity with a V/C ratio of 1.08 (1 lane blocked) or 1.66 (2 lanes blocked). The excess demand would not be served as desired, but would accumulate to form a queue starting at the incident link and moving toward upstream links. As the V/C ratio suggests, the effect of the 2-lanes-blocked incident was expected to be severe, whereas the 1-lane-blocked incident would have relatively small effect on the network.

The average V/C ratio along the diversion route on the inbound frontage road was estimated as 0.23. This ratio indicates that the frontage road has some unused capacity available for diverted traffic.

Delay Due to the Incident

The magnitude of delay caused by the incident can be quantified by subtracting the delay under the normal traffic condition (scenario 1) from the delay under the incident condition (scenarios 2 and 3). The total network delay increased by 10 percent and 53 percent for the 1-lane-blocked and 2-lanes-blocked incidents, respectively. The delay increased mostly on the freeway. The arterial streets were not greatly affected by the incident.

Table 1. Summary of Simulation Results for the Small Network

| Scenario | | Diversion, % | Delay, vehicle-hours | | |
|----------|--|-----------------|----------------------|--------|-------|
| | | | FREFLO | NETFLO | TOTAL |
| 1 | Normal | 0 | 20 | 624 | 644 |
| 2 | 1-lane-blocked Incident | 0 | 88 | 621 | 709 |
| 3 | 2-lanes-blocked Incident | 0 | 310 | 675 | 985 |
| 4 | 1-lane-blocked Incident Diversion with Existing Signals | 2 | 68 | 631 | 699 |
| | | 4 | 38 | 633 | 671 |
| | | 5 | 28 | 683 | 710 |
| | | 10 | 21 | 722 | 743 |
| 5 | 1-lane-blocked Incident Diversion with Optimized Signals | 2 | 66 | 448 | 513 |
| | | 4 | 36 | 479 | 515 |
| | | 5 | 25 | 489 | 514 |
| | | 10 | 18 | 535 | 553 |
| 6 | 2-lanes-blocked Incident Diversion with Existing Signals | 5 | 234 | 712 | 947 |
| | | 10 | 196 | 745 | 940 |
| | | 12 | 179 | 767 | 946 |
| | | 15 | 153 | 867 | 1020 |
| | | 20 | 140 | 946 | 1086 |
| 7 | 2-lanes-blocked Incident Diversion with Optimized Signals | 5 | 227 | 536 | 763 |
| | | 10 | 194 | 565 | 759 |
| | | 12 | 177 | 585 | 762 |
| | | 15 | 150 | 606 | 756 |
| | | 20 | 141 | 659 | 800 |

Optimal Diversion Percentage for 1-Lane-Blocked Incident

In order to find the optimal diversion percentage, multiple simulation runs were conducted. Each diversion strategy (each having the different diversion percentage) requires a separate input file. The curves in Figure 7 were constructed using the results for each diversion percentage. The curves show the relationship between the diversion percentage and the total network delay for the 1-lane-blocked incident. The upper curve represents the existing signal timing plan (scenario 4), and the lower curve represents the optimized signal timing plan (scenario 5). In general, the total network delay decreases as the diversion percentage increases until it reaches the minimum point, and then increases rather rapidly.

The optimal diversion percentage with the existing signal timing plan is approximately 4 percent, which is 234 vehicles per hour. By diverting 4 percent of the freeway through-traffic, the total delay was decreased by 5.4 percent.

In comparison with the existing signal timing plan, the optimized signal timing plan considerably reduced the total delay. Delay is not very sensitive to the diversion percentage when signal timing is optimized for each diversion percentage. Total delay remains almost constant for a range of diversion percentage (0 to 5 percent, approximately). Over this range of diversion percentage, the increase in arterial delay on the frontage road estimated by NETFLO Level 2 is equivalent to the decrease in freeway delay estimated by FREFLO. Given constant network-wide total delay, however, the diversion is still meaningful in terms of providing the more favorable operating condition for the freeway. Four-percent diversion along with the optimized timing plan produced 27.4 percent lower total network delay than the total delay for no diversion with the existing signal timing plan.

Figure 8 shows the relationship between the diversion percentage and the delay for each subnetwork. The freeway delay decreases with diversion percentage. Two curves, each representing the freeway delay with existing and optimized signal timings, respectively, overlap since the freeway was not affected by signal optimization for the frontage road. The arterial delay increases uniformly with diversion percentage.

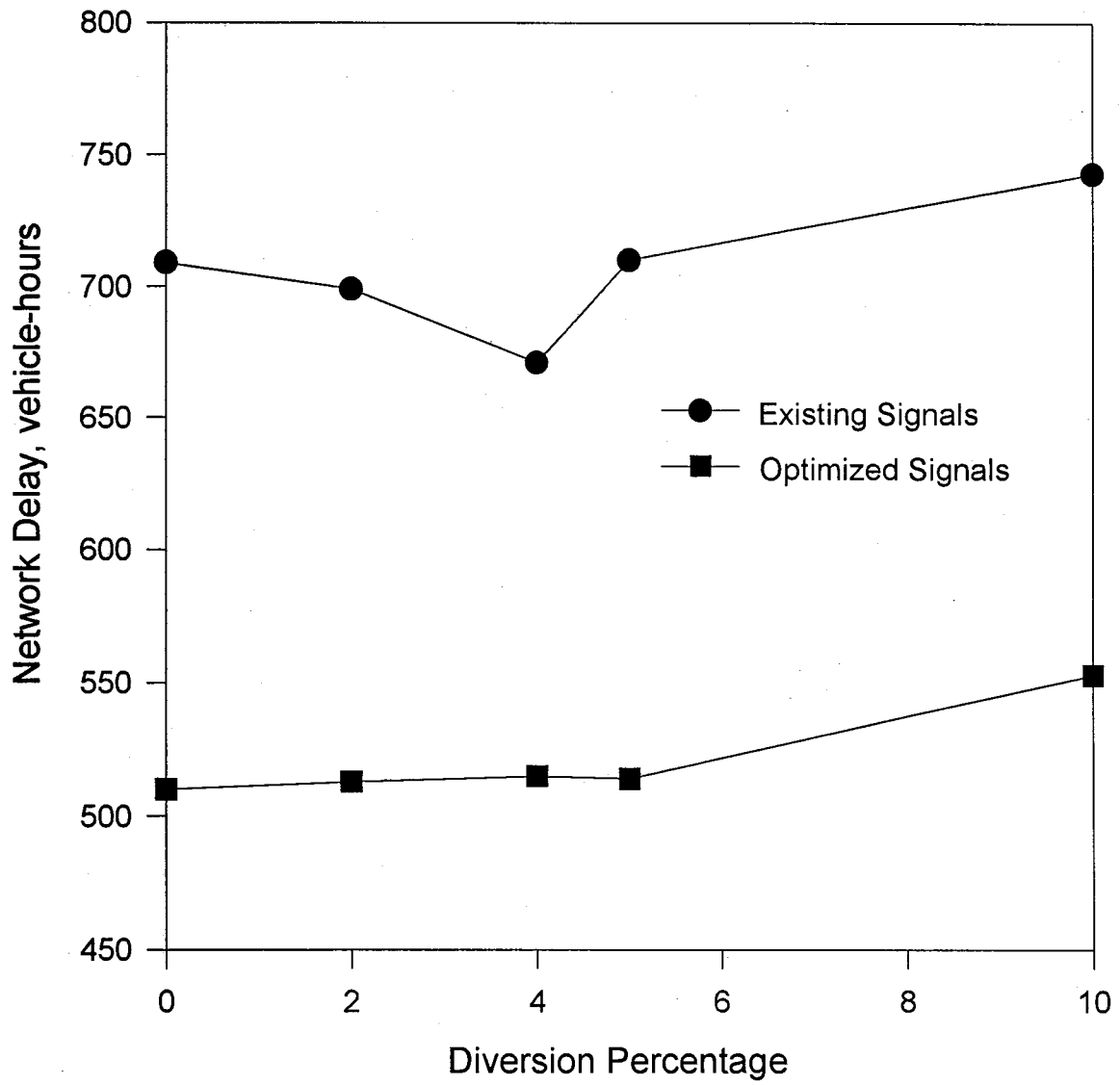


Figure 7. Diversion Percentage versus Total Network Delay for the 1-Lane-Blocked Incident

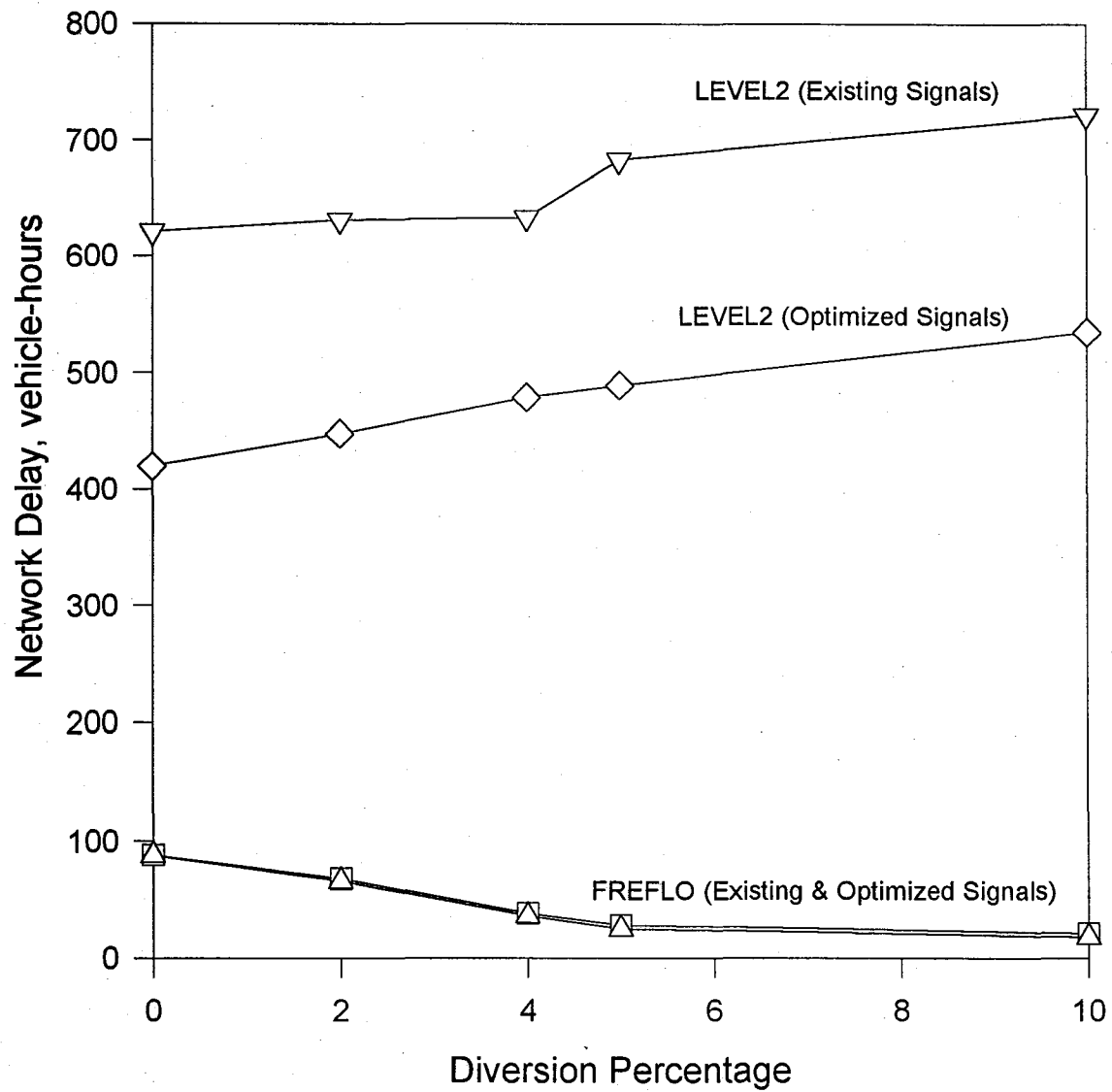


Figure 8. Diversion Percentage versus Subnetwork Delay for the 1-Lane-Blocked Incident

Optimal Diversion Percentage for 2-Lanes-Blocked Incident

Figure 9 illustrates the relationship between the diversion percentage and the total network delay for the 2-lanes-blocked incident. As with the 1-lane-blocked incident, the upper curve represents the existing signal timing plan (scenario 6), and the lower curve represents the optimized signal timing plan (scenario 7). Figure 10 illustrates the relationship between the diversion percentage and the delay for each subnetwork.

The optimal diversion percentage with the existing signal timing plan was approximately 10 percent, which is 586 vehicles per hour. Diverting 10 percent of freeway through-traffic decreased the total network delay by 4.6 percent.

As shown in Figure 9, the optimal diversion percentage with the optimized signal timing plan ranges from 5 percent to 15 percent. Ten-percent diversion (determined as the optimal diversion percentage for the existing timing plan) along with the optimized timing plan decreased the total network delay by 22.9 percent.

Benefits from Frontage Road Signal-Coordination

For the 1-lane-blocked incident, coordinating (optimizing) the frontage road signals along the diversion route increased the total network delay savings by 22.0 percent. Similarly, for the 2-lanes-blocked incident, signal coordination increased delay savings 18.3 percent. However, the optimal diversion percentages remained the same even after signal coordination. This might be due to the fact that the same cycle length was retained for both existing and coordinated signal timing plans.

Efficiency of Diversion Strategies

The efficiency of a diversion strategy depends upon how close the strategies can keep the system performance to the normal condition. The efficiencies of the strategies represented by scenarios 4 to 7 can be estimated as following:

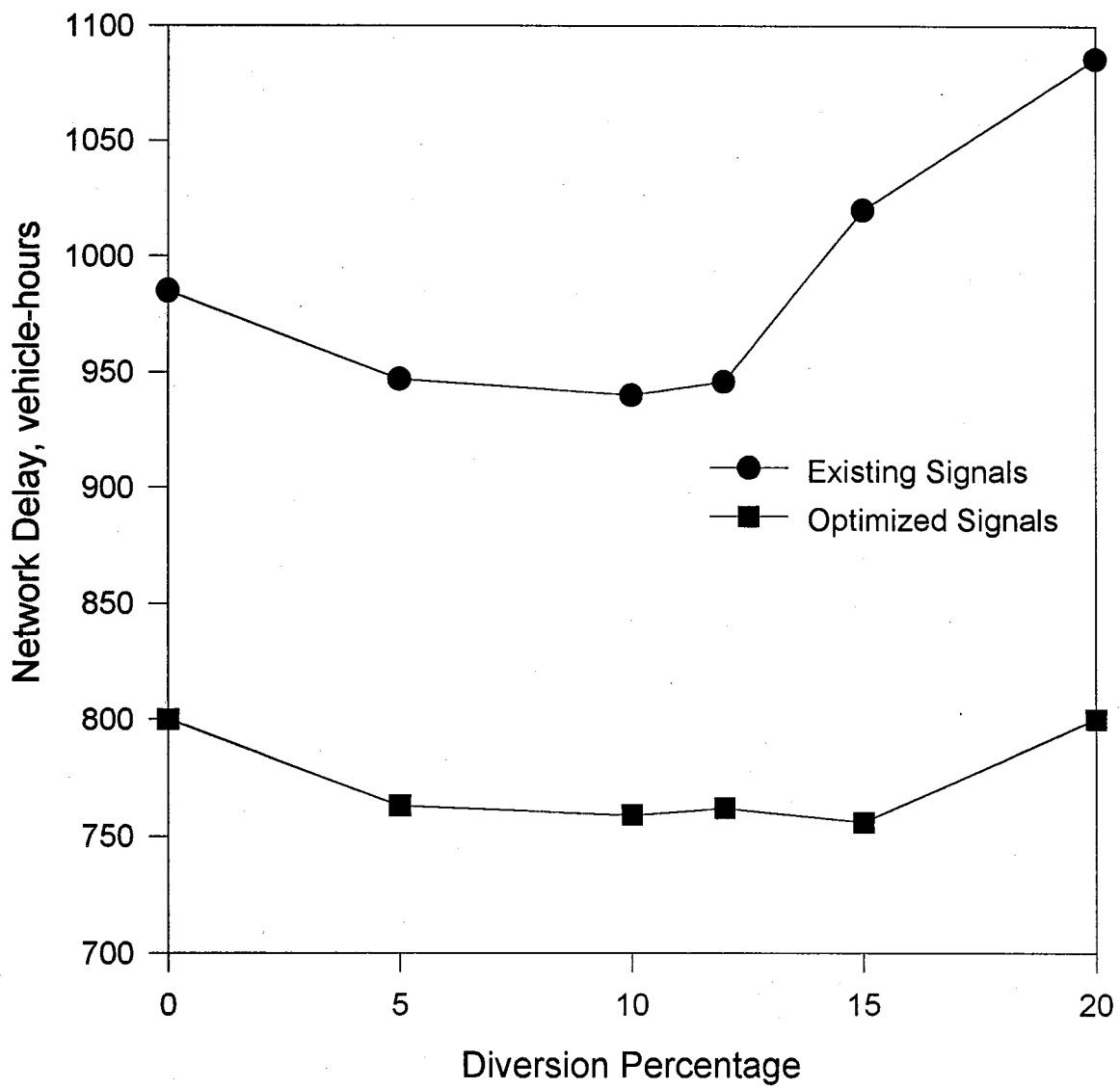


Figure 9. Diversion Percentage versus Total Network Delay for the 2-Lanes-Blocked Incident

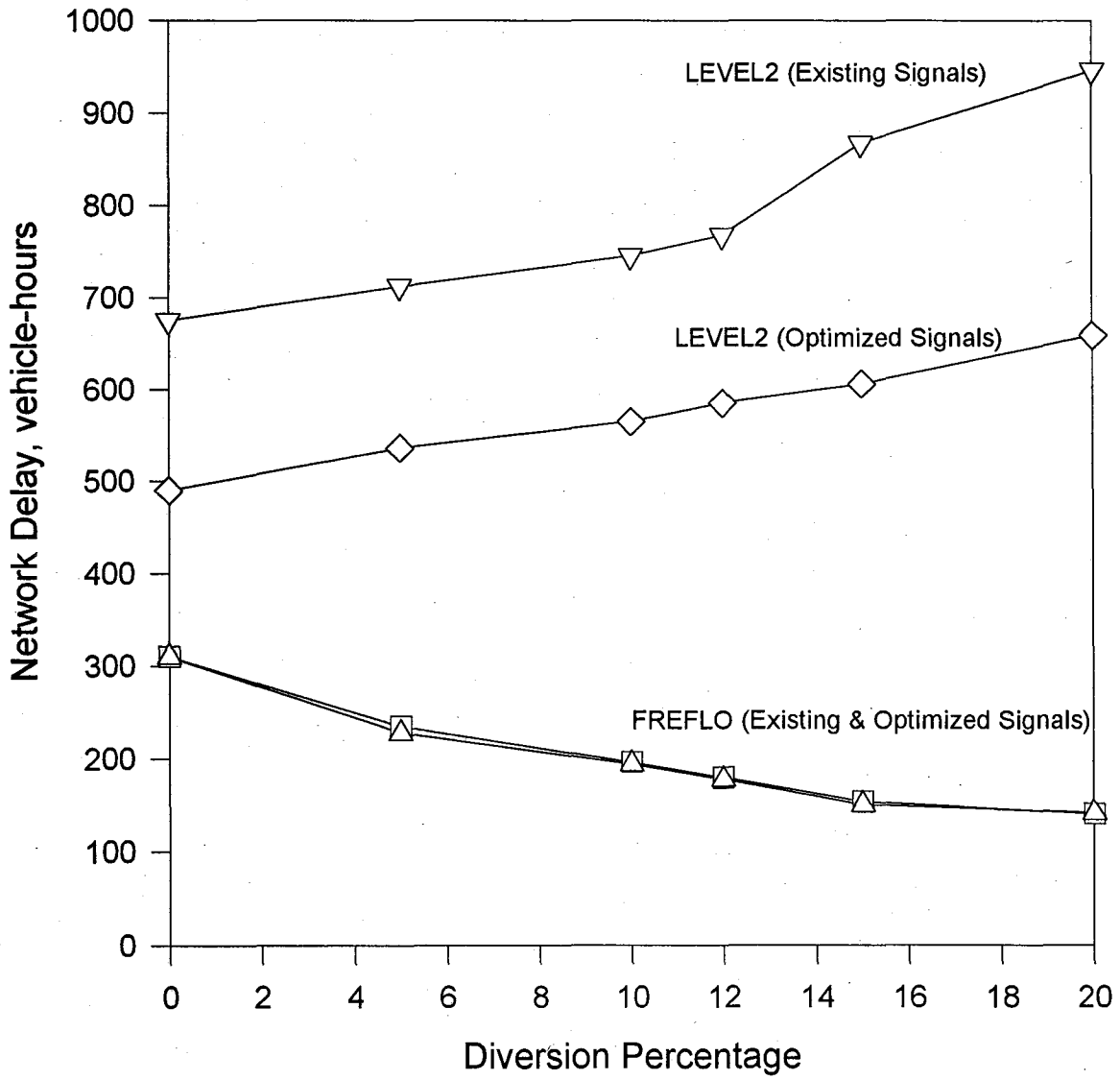


Figure 10. Diversion Percentage versus Subnetwork Delay for the 2-Lanes-Blocked Incident

$$\text{Efficiency (\%)} = (\Delta D_b / \Delta D_i) \times 100 \quad (1)$$

where, ΔD_i = Delay induced by the incident = (Delay with the incident) - (Delay in normal condition)

ΔD_b = Delay reduced by diversion = (Delay with the incident) - (Delay with the diversion strategy)

The efficiency of each diversion scenario was computed as follows:

- Scenario 4: Efficiency = $\{(709-671) / (709-644)\} * 100 = 58.5$ percent;
- Scenario 5: Efficiency = $\{(709-515) / (709-644)\} * 100 = 298$ percent;
- Scenario 6: Efficiency = $\{(985-940) / (985-644)\} * 100 = 13.2$ percent; and
- Scenario 7: Efficiency = $\{(985-759) / (985-644)\} * 100 = 66.3$ percent.

The efficiency of a diversion strategy is improved considerably by using an optimized signal timing plan. The efficiency was increased from 58.5 to 298 percent for the 1-lane-blocked incident, and from 13.2 to 66.3 percent for the 2-lanes-blocked incident. For scenario 5, the efficiency was greater than 100 percent, which means that by optimizing signal timing, the system operates more efficiently than the normal condition even though there is an incident. In other words, the system experiences unnecessary delay under normal conditions. Signal coordination is desirable to improve system performance even under normal conditions.

ANALYSIS WITH THE LARGE NETWORK

The more complete US-59 Southwest Freeway corridor network was used for this analysis. Basically the same methodology was applied, but this analysis targets certain origin-destination pairs for diversion instead of varying diversion percentages. The objective was to determine how much delay network-wide diversion and local diversion can save for different levels of incident severity. Network-wide diversion refers to the optimal travel pattern throughout the network (as determined by the TRAFFIC assignment model) based on the incident condition. Local diversion refers to diversion to specified routes within the corridor.

Analysis Scenarios

The following scenarios were developed for simulation runs:

- Scenario 1: off-peak period traffic, normal condition without incident;

- Scenario 2: off-peak period traffic, half-hour 2-lanes-blocked incident with the same link volumes as the normal condition (no diversion);
- Scenario 3: off-peak period traffic, half-hour 3-lanes-blocked incident with the same link volumes as the normal condition (no diversion);
- Scenario 4: off-peak period traffic, half-hour 2-lanes-blocked incident, a local diversion strategy in effect;
- Scenario 5: off-peak period traffic, half-hour 3-lanes-blocked incident, a local diversion strategy in effect;
- Scenario 6: off-peak period traffic, half-hour 2-lanes-blocked incident, a network-wide diversion strategy in effect; and
- Scenario 7: off-peak period traffic, half-hour 3-lanes-blocked incident, a network-wide diversion strategy in effect.

Simulation Runs

The total simulation period was 2 hours (from 2:00 to 4:00 P.M.). Figure 11 shows the assumed incident location. This freeway section has 4 lanes in each direction. The incident occurred at 2:00 P.M. in the inbound direction and continued until 2:30 P.M. Also shown in Figure 11 are the routes for local diversion that include 2 exit ramps, 2 parallel streets, and 2 entrance ramps. The diverting traffic passed through seven signalized intersections on the first route and nine on the second route. In this analysis, specific origin-destination pairs were targeted for diversion. In total, 800 vph were diverted among the trips originating in the southwest area of the network (including trips entering the network via US-59) and destined for IH-610 North. These trips, if not diverted, would travel along US-59 North and exit to IH-610 immediately after passing through the incident link. Diversion was simulated for 30 minutes during the same time period as the incident period (2:00-2:30 p.m.). Network-wide diversion was simulated by letting TRAFFIC assign the traffic volumes based on the incident condition. This was achieved by specifying the incident condition in the first simulation time period of the CORFLO input file, since TRAFFIC assigns trips onto the network based on the network condition specified in the first time period.

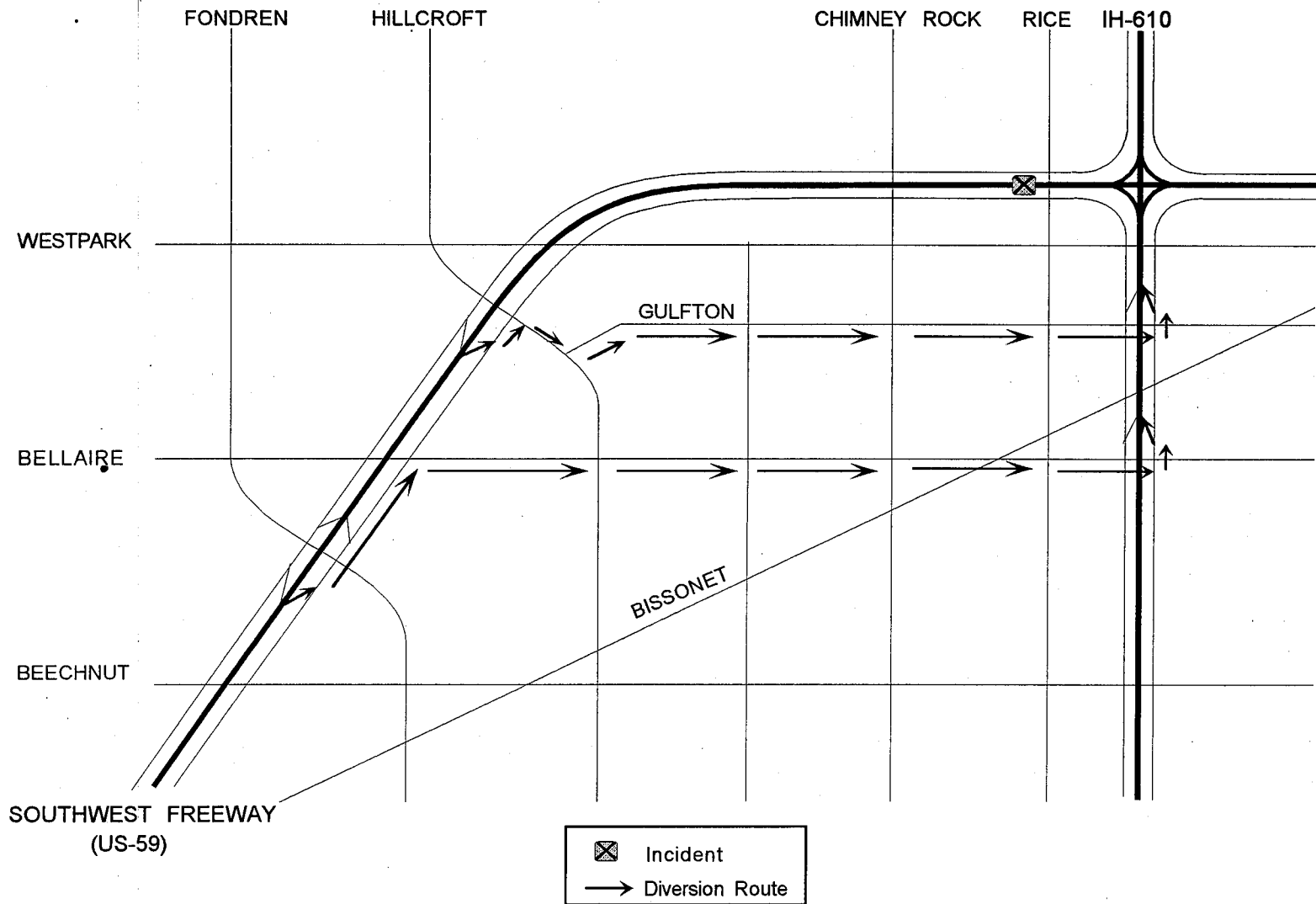


Figure 11. Schematic of the Incident Location and the Diversion Route

Methodology for Comparison and Evaluation

Possible comparisons and corresponding measures in question are as follows:

- Scenario 1 versus Scenarios 2/3: maximum delay due to the incident;
- Scenarios 2/3 versus Scenarios 4/5: delay savings due to diversion strategies;
- Scenarios 2/3 versus Scenarios 6/7: delay savings due to network-wide diversion; and
- Scenario 1 versus Scenarios 4/5 and 6/7: efficiency of diversion strategies in terms of how close the incident condition is to the normal condition (no incident).

Results

Table 2 summarizes the simulation results from CORFLO runs with the set of scenarios. Under normal condition without incident (scenario 1), the network conditions are good with no major congestion areas.

The demand at the assumed incident link was 7,093 vph, which is slightly below the capacity (8,000 vph), and thus may normally experience moderate congestion. An incident would reduce the capacity of the link from 8,000 vph to 2,960 (2-lanes blocked) or 2000 vph (3-lanes blocked). As a result, the demand would greatly exceed the capacity for both incidents. The excess demand would not be served as desired, but would accumulate to form a queue starting at the incident link and moving toward upstream links. As the V/C ratio suggests, the effect of the 3-lanes-blocked incident was expected to be severe, whereas the 2-lanes-blocked incident would have modest effect on the network.

The excess through-capacity available for diverted traffic along the two diversion routes (Gulfton and Bellaire) was estimated to be 394 and 377 vph, respectively. These values indicate that the diversion routes can accommodate some additional traffic diverted from the freeway.

The increases in travel time were 3,902 vehicle-hours for the 2-lanes-blocked incident and 4,315 vehicle-hours for the 3-lanes-blocked incident. The total network travel time (and thus delay) increased 14 percent and 16 percent for the 2-lanes-blocked and 3-lanes-blocked incidents, respectively. Due to the increased network size, the percentage increase is relatively small compared to the analysis of the small network. The delay increased mostly on the freeway. The arterial streets were not greatly affected by the incident.

The percent delay savings from the local diversion strategy were 6 percent for the 2-lanes-blocked incident and 24 percent for the 3-lanes-blocked incident. The network-wide

Table 2. Summary of Simulation Results for the Large Network

| Scenario | | Travel Time in vehicle-hours | | |
|----------|--|------------------------------|--------|-------|
| | | FREFLO | NETFLO | TOTAL |
| 1 | Normal | 8009 | 19670 | 27679 |
| 2 | 2-lanes-blocked Incident | 11249 | 20332 | 31581 |
| 3 | 3-lanes-blocked Incident | 11327 | 20667 | 31994 |
| 4 | 2-lanes-blocked Incident Local Diversion | 11012 | 20342 | 31354 |
| 5 | 3-lanes-blocked Incident Local Diversion | 10178 | 20762 | 30940 |
| 6 | 2-lanes-blocked Incident | 10485 | 19834 | 30319 |
| 7 | 3-lanes-blocked Incident Network-wide Diversion | 9161 | 19423 | 28584 |

diversion strategy provided delay savings of 32 percent for the 2-lanes-blocked incident and 79 percent for the 3-lanes-blocked incident.

The efficiency of each diversion scenario was computed as follows:

- Scenario 4: Efficiency = $\{(31581-31354)/(31581-27679)\} * 100 = 5.8$ percent;
- Scenario 5: Efficiency = $\{(31994-30940)/(31994-27679)\} * 100 = 24.4$ percent;
- Scenario 6: Efficiency = $\{(31581-30319)/(31581-27679)\} * 100 = 32.3$ percent; and
- Scenario 7: Efficiency = $\{(31994-28584)/(31994-27679)\} * 100 = 79.0$ percent.

It is noteworthy that the efficiency of the network-wide diversion strategy is considerably greater than the local diversion strategy. The efficiency increased from 5.8 to 32.3 percent for the 2-lanes-blocked incident, and from 24.4 to 79.0 percent for the 3-lanes-blocked incident. The efficiency of diversion strategies was greater when the incident was more severe. This indicates that diversion strategies can reduce a larger proportion of incident-induced delay when the incident is more severe.

FINDINGS FROM THE CASE STUDY

The capacity reduction caused by the lane-blocking incident resulted in a significant increase in total network delay. The 2-lanes-blocked incident, for example, caused a 50 percent increase in delay for the small study network.

The relationship between diversion percentage and total network delay was represented as a flat parabolic curve when plotted. There existed an optimal point where the total network delay is minimum. This point represents the optimal volume of traffic to be diverted from the freeway. The optimal diversion percentage for the small study network ranged from 4 to 10 percent. The total network delay was minimized by diverting the optimal percentage of the freeway through-traffic to the frontage road. Delay savings were significantly increased when the frontage road signal timing was optimized. The signal coordination provided great advantages in accommodating the diverted traffic. The results are only applicable for the study network and should not be directly used for other networks with different corridor configurations, traffic conditions, or incident characteristics. However, the general shape of the diversion-delay relationships is expected to be common to most freeway corridors.

The optimal diversion percentage is controlled by a combination of the influencing factors including: corridor configuration, demand pattern, incident characteristics, diversion route choice, diverting location, entry location, time lag between incident detection and diversion, signal timing, and other supporting controls such as the ramp metering or closure. Given a combination of the influencing factors, the optimal diversion percentage depends on the availability of excess capacity on the alternative diversion route. In a small corridor where availability of alternative routes is very limited, diversion opportunities during the peak period are very rare because the available alternative route would also be congested. In such cases, diversion strategies would be more beneficial when implemented during the off-peak period when the route is less congested. On the other hand, a moderately large corridor with more diversion opportunity will gain more benefits from diversion during peak periods since the impact of the incident is much more severe during peak periods.

If a diversion route contains many signalized intersections, the signals should be coordinated to facilitate the movement of the diverted traffic and improve the system performance. Otherwise, diversion is not likely to provide much benefit, especially when the diversion route is congested.

The analysis of the large network illustrates two diversion strategies, referred to as local and network-wide diversion. The local diversion strategy identifies origin-destination pairs with large volumes of trips that would be affected by the incident and targeted specific diversion routes for them. Targeting selected origin-destination pairs may have practical advantages in providing information and implementing signal timing changes on a limited number of alternative routes. The network-wide diversion strategy represents the ideal of traffic assigned to routes in the corridor based upon user equilibrium principles; it represents the standard against which more limited diversion strategies should be compared. It is unlikely that the user-equilibrium assignment could be achieved during an incident because it requires all drivers to have complete knowledge of conditions.

DISCUSSION AND RECOMMENDATIONS

This case study is a representative example of corridor-scale analysis of traffic management alternatives for incident management using the guidelines suggested in Chapter 4. This section discusses practical aspects of analysis using CORFLO based upon experiences gained from this case study and another modeling study of the US-75 North Central Expressway corridor in Dallas.

Network building and coding require a major modeling effort. An analyst would need to make a moderate initial effort to get acquainted with the coding schemes required by CORFLO, and to learn the necessary techniques for translating the physical roadway geometry into the coded representations. The actual coding would be slow initially, but gradually expedited as the coder's skill improves. Nevertheless, it is always a time-consuming task. For the Houston network in this case study, it took approximately 3 person-months to build the network after the necessary data had been obtained. In the case of the Dallas network (which is approximately three times larger than the Houston network in terms of number of nodes and links), it took more than 12 person-months to obtain the data and complete the coding job.

The trip table for CORFLO can be obtained through the windowing process available either through the Texas Travel Demand Package or TRANPLAN, the regional planning packages used in Texas. The windowing process requires a series of complicated manual and computer tasks. For relatively small networks, this job does not entail serious difficulties. However, PC-based planning models such as TRANPLAN cannot handle large networks if the number of the cordons links to be processed during the windowing process is greater than the maximum allowable, which is

approximately 110 one-way links. In this case, a planning model for mainframe computers such as the Texas Travel Demand Package must be utilized.

After a network is built and the trip table is prepared, it is difficult to make changes, especially when it involves the addition or deletion of origin-destination zones, since the trip table must be regenerated for the modified network. Therefore, caution should be exercised when laying out the zones to minimize the additional efforts due to network modifications. Any modifications, if imperative, should be done before model calibration.

Calibration requires significant data and resources, but often the amount of data and resources available are limited. For the Houston network, only network calibration was performed, because sufficient data were not available for the calibration of assigned link flows. For the Dallas network, calibration of assigned link flows involved factoring the trip table (based on ground counts on cordon links) and adjusting selected origin-destination pairs that use particular sections of the roadway (based on the differences between the assigned volume and ground count on that section). Tables 3 and 4 summarize the link differences resulting from calibration for the Houston and Dallas networks. The calibration results indicate a reasonable match for the purpose of the study, considering the limited amount of data used for calibration.

Table 3. Calibration Results for the US-59 Southwest Freeway in Houston

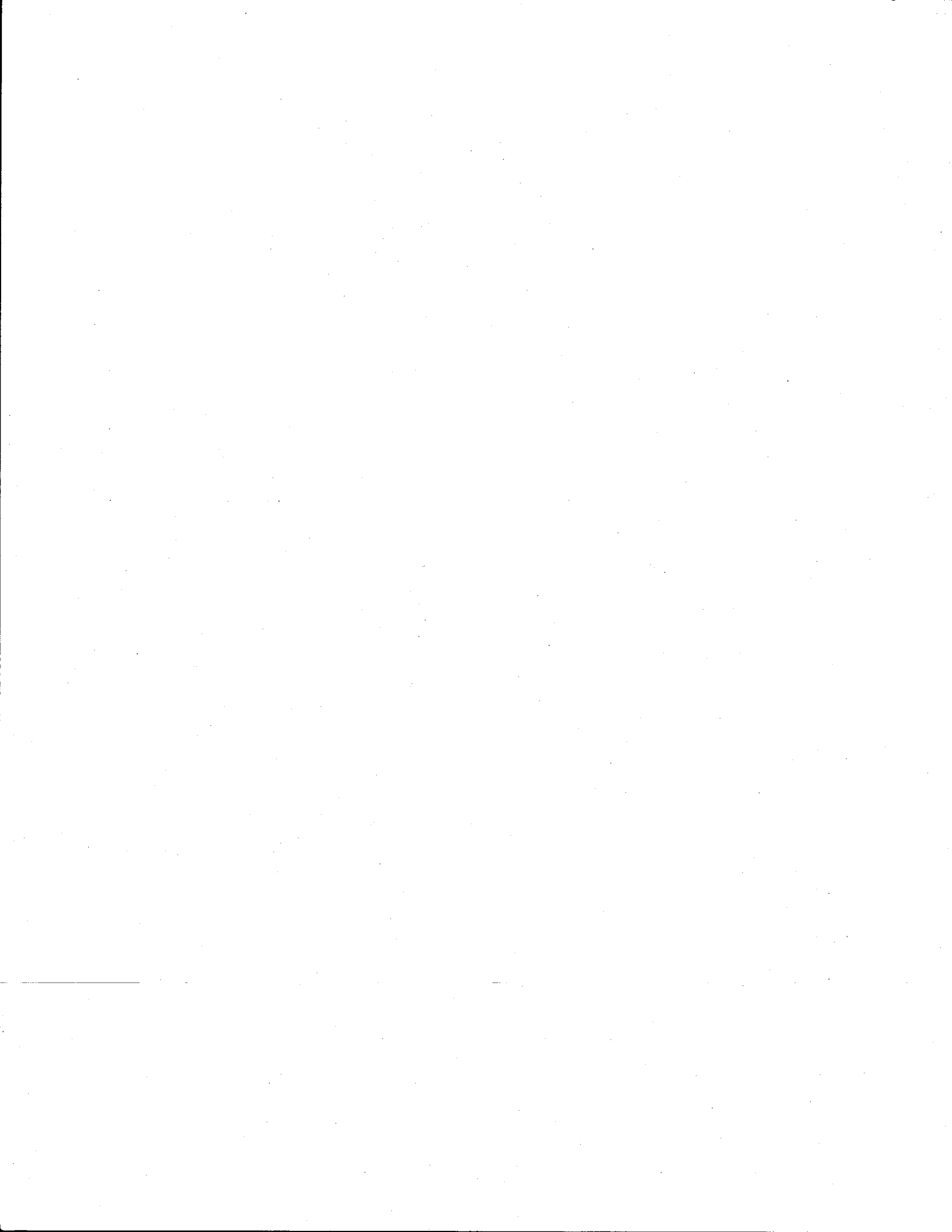
| Percent Difference* | <10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | >100 |
|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Frequency | 69 | 56 | 34 | 27 | 27 | 19 | 19 | 11 | 2 | 14 | 27 |
| Cumulative Frequency | 69 | 125 | 159 | 186 | 213 | 232 | 251 | 262 | 264 | 278 | 305 |
| Cumulative Percent | 23 | 41 | 52 | 61 | 70 | 76 | 82 | 86 | 87 | 91 | 100 |

$$* \text{ Percent Difference (\%)} = \frac{|\text{observed ground count} - \text{assigned link volume}|}{\text{observed ground count}} \times 100$$

Table 4. Calibration Results for the US-75 North Central Expressway in Dallas

| Percent Difference* | <10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | >100 |
|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| Frequency | 94 | 25 | 16 | 22 | 12 | 7 | 11 | 8 | 5 | 3 | 8 |
| Cumulative Frequency | 94 | 119 | 135 | 157 | 169 | 176 | 187 | 195 | 200 | 203 | 211 |
| Cumulative Percent | 45 | 56 | 64 | 74 | 80 | 83 | 89 | 92 | 95 | 96 | 100 |

$$* \text{ Percent Difference (\%)} = \frac{|\text{observed ground count} - \text{assigned link volume}|}{\text{observed ground count}} \times 100$$



VI. CONCLUSIONS AND RECOMMENDATIONS

Corridor traffic simulation models are versatile tools capable of estimating the corridor traffic conditions resulting from incidents and various management strategies. With proper caution, an experienced analyst can take full advantage of the simulation models when developing corridor traffic management strategies for freeway incidents.

This report focused on corridor analysis for incident management using the CORFLO model. Corridor-scale analyses using corridor traffic simulation models have the important advantage of being able to evaluate the effects of incidents and alternative traffic management strategies on all affected routes throughout a corridor within a single modeling environment. Therefore, it is recommended that Chapter 8, "Traffic Operations Analysis," of the *Texas Highway Operations Manual (2)* be revised to include a more complete discussion of the corridor analysis guidelines presented in this report.



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