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Considerations in the Application
of Freeway Computer Simulation Models
to Project Evaluation

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Research Report 1232-11

Research Study Number 2-18-90/4-1232

Sponsored By

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

December 1992

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
In	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
AREA				
In²	square inches	645.2	centimetres squared	cm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
MASS (weight)				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
VOLUME				
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
AREA				
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectares (10 000 m²)	2.53	acres	ac
MASS (weight)				
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

°F   -40   32   98.6   212
       0   40   80 120 160 200
°C   -40 -20   0   20 40 60 80 100
                        37
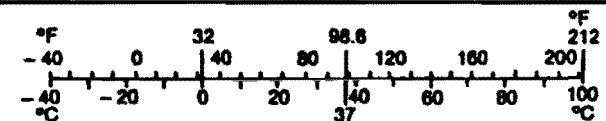
These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

EXECUTIVE SUMMARY

The cost of roadway construction projects requires that the engineer or planner have exceedingly accurate predictions of the operations resulting from a proposed freeway project. Analysis of complex geometrics is performed with the assistance of computers. The computer programs used to perform an analysis provide many advantages over manual evaluation. However, the user should thoroughly understand the simulation process and candidate models before any data is collected or input. This report is to be used to aid in simulation selection, analysis planning and application of freeway simulation models.

This report defines the internal characteristics of a number of freeway simulation models. These characteristics include: traffic stream representation, analysis basis, and analysis objective. The approach to the modelling process should include identification of the study limits, measures-of-effectiveness desired and available computer hardware. Once the model has been chosen, the data should be collected and the base case (existing conditions) simulation performed. A calibration should also be performed to replicate actual conditions. Simulations of the proposed alternatives can then be compared to the base case.

The input, output, difficulties encountered, and a list of possible applications of the HCS, FREQ, FREFLO, CORFLO, INTRAS and FRESIM simulation models are presented. A table is also shown with various project applications and the recommended model.

A case study was selected to display the attributes of the basic assumptions (default values) for each of the models. The FREQ, FREFLO/CORFLO, and INTRAS models do produce reasonable results, but do not exactly replicate the actual speeds. HCS produced the least accurate operational results of the models tested.

ABSTRACT

Improvements or new construction of freeways can benefit from tools to evaluate various design alternatives. The use of a computer model to evaluate project alternatives is the most cost effective method, but often times the least understood. This research study focuses on characteristics of and the process of choosing a freeway simulation model. The input, output and possible applications of several freeway simulation models are listed and a case study highlighting the output from each model is presented for comparison. Finally, a ranking of the freeway models is presented for particular applications.

DISCLAIMER

IMPLEMENTATION STATEMENT

This report may be used by individuals involved in the planning or design of freeway segments or systems. Freeway simulation terminology is reviewed and a methodology is presented which may be used to guide a freeway analysis. Individual model characteristics are summarized and recommendations are presented for model usage. The implementation of the analysis methodology and model application recommendations will provide a systematic approach to freeway analysis.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Growing automobile demand in combination with aging roadway facilities is prompting the reconstruction and upgrading of many freeways in congested urban areas. Retrofitting and redesigning the existing freeway system to accommodate the growing volume of traffic while operating within constrained right-of-way presents the freeway designer with challenging design problems. The planners and engineers are no longer restricted by the lack of a mechanism for testing their ideas prior to field demonstration. The availability of traffic simulation models greatly expands the opportunity for the development of new and innovative transportation management concepts and designs. The models also produce information which allows the freeway designer to identify the weaknesses in concepts and design.

Traffic simulation models can be used to evaluate conditions on urban streets, freeways, frontage roads, rural roads and complete highway systems. When the analysis is simple, manual methods are often less time consuming than computer analysis. However, as situations become more complicated, the computational speed of the computer becomes important. The models are significant tools for simulating complex roadway situations where a number of roadway variables are influencing one another. Computer simulation models should be used when there is a large number of calculations or when repeated analyses are performed with only minor changes in the input variables.

There are several steps involved in using a computer simulation model to perform an analysis. Steps that are necessary include, data collection, input coding, and calibration. However, the most important step in any analysis is the proper decision of which simulation model to use. This report summarizes the characteristics and some of the considerations necessary before applying freeway computer simulation models.

1

MODELLING APPROACH

An assortment of freeway simulation models is currently available for operational analysis. The characteristics of the models determine how a procedure is categorized and provide the user with some information on possible applications. The various model characteristics can be classified by:

- o Traffic Stream Representation
- o Analysis Basis
- o Analysis Objective
- o Randomness

Traffic Stream Representation

The manner in which the traffic stream is represented is a simulation model's most significant characteristic. The two approaches used are macroscopic, where the traffic stream is represented by a homogenous aggregate group; or microscopic, where individual vehicles are simulated.

Macroscopic - A macroscopic simulation model represents traffic in terms of total measures on each section of freeway. The measures often used are flow rate, density and space-mean-speed. Macroscopic models most often use an equilibrium speed-density or speed-flow relationship derived from empirical data.

Microscopic - Microscopic simulations model the traffic stream explicitly; each vehicle on the network is treated as an identifiable entity based on car-following behavior. Individual vehicle attributes such as vehicle type, driver behavioral characteristics, speed/acceleration, turning movements, free flow speed and mean queue discharge headways are also assigned stochastically. Consequently, each vehicle's behavior may be simulated in a stochastic manner, reflecting real-world processes.

2

Analysis Basis

The simulation algorithms can be based on previous observations or experiments, or on a mathematical methodology using numerical relationships.

Empirical Analysis - If a simulation is based upon previous experience or field data then it is an empirical analysis. Empirical models are most often macroscopic in nature since the traffic stream is modelled in aggregate. Empirical models use summary tables, charts and nomographs to produce a representation of traffic operations.

Analytical Analysis - If the simulation uses mathematical relationships or other basic principles it is an analytical analysis. Analytical models are based on theoretical formulas and relationships. Microscopic models use an analytical approach in representing the traffic stream.

Analysis Objective

Freeway simulation models have two objectives - 1) to simulate or reproduce traffic operations for a certain network and traffic demand or 2) to produce a ramp metering plan that optimizes some freeway operational parameters. When the analysis attempts to reproduce traffic operations, it is called a simulation. Simulations may be used to evaluate the before and after effect of some geometric or demand related strategy. When the analysis attempts to enhance traffic operations, it is called an optimization. An optimization may be used to generate, evaluate and select alternative entry control strategies.

Randomness

The fact that humans are involved in the operations of the traffic stream dictates that some degree of randomness will occur. Modelling randomness is a tedious task and requires large computational times. When randomness is introduced into a procedure the process is considered stochastic. The outcome of a stochastic simulation varies each time the program is executed. When a simulation produces the same outcome every time it is executed (for a given input set) the process is considered deterministic.

MODEL USAGE

Freeway simulation models provide the highway engineer or planner with a method for evaluating the impact that geometric changes or control strategies have on traffic operations. Changes such as lane closures, ramp addition or removal, lane widening or shoulder removal, HOV operations, and ramp metering will all effect freeway travel time, operating speeds, queue length and patterns, and alternative routes. The results of these changes are quantified by the freeway simulation models and provide a way for the engineer to objectively rate or rank the various alternatives based on its generated measures of effectiveness. The following sections discuss important aspects which must be considered before deciding which freeway simulation model is the most appropriate for the task

SELECTION OF THE MODEL
Identify the Study Limits
The study site should include all segments likely to experience changes in travel patterns or operations. The study site may be confined to only one direction, or the problem may require the simulation of a larger portion of the roadway system. Congestion at an isolated location may appear to be curable by some geometric change, when in fact, such a change will simply move the congestion downstream to the next bottleneck which was obscured by the congestion at the first. For this reason, it is advisable that the engineer or planner study not only the specific site that requires attention, but also segments upstream and downstream. Upstream limits should include all existing or projected congestion. Downstream limits should also include any existing or projected locations of congestion. The size of the study section will influence the selection process.

Identify MOE's Desired
Depending upon the purpose of the simulation, the measures-of-effectiveness/level of detail produced by the models may govern their application. For example, if freeway level of service (LOS) is desired, a model that produces density may be used to translate vehicles/mile to LOS. The selection of a simulation is influenced by the MOE's required

for the evaluation of an alternative.

Identify Available Computer Hardware

Computer hardware available to the user may dictate the model of choice. Some programs are currently only available for use on a mainframe computer. The simulation programs currently under development are being written for desktop PC's. The more detailed microscopic programs require PC's with large hard-drives, math coprocessors and high clock speeds.

SIMULATION METHODOLOGY

Once the choice of which model to use has been decided and using the information gathered in selecting the model, the following methodology for applying any of the simulation models should be followed.

Define and Collect Existing Characteristics

Several types of data need to be collected in order to define the existing traffic operations and roadway characteristics of the study site. This data will be used as input and to "calibrate" a base case simulation, against which alternatives may be evaluated.

- o Roadway geometric data (number of lanes, ramp configuration, grade, etc.)
- o Entering and exiting volume counts need to be collected as they are required inputs into all of the models.
- o Traffic composition by vehicle type and auto occupancy may also be essential.
- o Average travel times and speeds should be collected to help define the base condition.
- o The capacity of each freeway segment needs to be estimated. Capacity has more impact on the simulation results than any other user supplied entry. The capacity of the links in the network may be estimated using traffic counts along the freeway (the capacity has to be at least as large as the maximum volume counted on that link) or using highway capacity analysis procedures if counts

are not available (see the Highway Capacity Manual). It is important to note that capacity can only be measured when no downstream congestion exists. Capacity of Texas freeways is typically 2200 pcphpl.

Calibrate Base Case Simulation

After the required data is entered into the appropriate model and the simulation is executed, the generated results are compared to field data. Adjustments to the link capacities or speed/flow or speed/density relationships may be necessary to generate freeway link volumes, travel times and speeds that are comparable to existing operations. If it is necessary to use capacities significantly less than 2000-2200 pcphpl, then it is likely that the study section does not include a controlling downstream bottleneck. Once comparable results are obtained, the initial simulation effort is known as the "base case" scenario.

Evaluate Alternatives

Alternative configurations, demands, or control strategies may then be entered and a simulation conducted. The alternative simulation MOEs are then compared to the base case MOE to determine the alternative's effectiveness.

FREEWAY SIMULATION MODELS

There are five simulation models currently available to evaluate freeway operations. These models are:

- Highway Capacity Software (HCS)
- FREQ
- FREFLO
- INTRAS
- CORFLO

One other model that is being developed and undergoing testing for the Federal Highway Administration (FHWA) is the FRESIM model.

This section will summarize required inputs, operational environment and limits, model output, and observed difficulties, as well as give example applications and recommended usages for each of the currently available models.

HIGHWAY CAPACITY SOFTWARE (HCS)

The Highway Capacity Software is a macroscopic, empirical, deterministic simulation that can be used to evaluate traffic flow at specific highway features. It is based on the 1985 Highway Capacity Manual (HCM). The procedures contained in the manual are widely accepted. The analysis procedures for the HCS are exactly the same as for the HCM, but the use of a computer allows for an almost instantaneous calculation and output.

The HCM describes the theory and methods for determining the level-of-service, capacity and service flow rates for various roadway segments. Three sections of the HCS specifically address the following aspects of freeways: basic freeway segments, weaving sections, and ramp, and ramp junctions.

HCS Input

Data is entered into HCS by simply following the instructions given on the menu driven data input screens. The user presses certain keys to choose the module to be executed (basic freeway segment, weaving area or ramp, or ramp junction). The data input screens then prompts the user for the required input. Depending on the module selected, the input may include: volumes, length of segment, number of lanes, percent trucks, percent buses and percent RV's, design speed, peak hour factor, lane width, and distance to closest obstructions. One aspect of HCS undergoing change is the upper limit of the roadway capacity. All calculations with HCS are currently based on a maximum roadway capacity of 2000 pcphpl; however, the Highway Capacity Committee has recommended that a value

7

of 2200 pcphpl be used in an upcoming interim update of the HCS. It is fairly common to find freeways with flow rates in excess of 2300 vphpl.

HCS Output

Output from the HCS program is limited to an echo of the input, the speed, level-of-service and density of the single freeway segment or ramp. The calculations are based on the speed/flow relationships presented in the HCM. The output (measures of effectiveness) is displayed on the computer screen and allows the user the option of printing.

Difficulties

Specific difficulties or inconveniences that were noted concerning the HCS program are listed below.

    o   From the "Weaving Areas" section of the main menu, the "Weave Type" qfn the user must have prior knowledge of the various weave configurations (Type A, B,or C), or must consult the Highway Capacity Manual (HCM). Some graphical or typed explanation would have better served the user.

    o   In the same section, under the "Volumes" option, the term **downweaving** and **upweaving** are confusing without a visual diagram.

    o   In the Basic Freeway Segments or Weaving Areas sections, under the "Adjustment Factors" option, the user must consult the HCM to obtain the proper value for the Driver Population Factor.

Application

The HCS simulation may be used on isolated segments of freeway. A ramp, a ramp junction, a weaving section or a single basic section of freeway (no ramps) may be evaluated. HCS may be used for a quick and simple spot analysis; however, it is not a good tool to use when evaluating the system effects of an alternative. The upper limit of the lane capacity of the model is currently well below the observed value of many urban freeways and results

8

in simulated operations much poorer than actual. However, even when appropriate capacities are used, the HCS <u>CAN</u> <u>NOT</u> evaluate system operations when demand exceeds capacity. If any section of a freeway operates at LOS F, a more detailed analysis using simulation is required to understand the overall system operations.

<u>FREQ</u>

The FREQ sequence of models initially originated around 1970 at the University of California-Berkeley (1) and has undergone a number of revisions guided by the Institute of Transportation Studies. The model is deterministic and macroscopic (i.e. for a given set of inputs the model will have completely predictable outcomes, and the model treats the traffic stream as a unit, instead of individual vehicles). FREQ was intended to be used to evaluate a directional freeway and its ramps on the basis of ramp origin-destination information. The model consists of two parts: a simulation component and an optimization component. The simulation component generates a mathematical model to approximate actual operating conditions. The optimization component can be used to generate, evaluate and select alternative entry control strategies (entrance ramp metering plans). After selecting a control strategy, the simulation component can be utilized to evaluate traffic performance under the new ramp metering strategy. The simulation component may also be used to evaluate the before and after effect of some geometric or demand-related alternatives. Other versions of FREQ may be used for evaluating proposed high-occupancy vehicle lanes. Throughout its development, the FREQ models have been widely applied and have received widespread validation.

Early versions of the FREQ model were written for mainframe computers, since this was the hardware available to execute relatively large FORTRAN programs. Of the freeway simulation models that are currently available for public use, FREQ is the only one that may be executed on a desktop PC. The particular version of FREQ that is used in this review is FREQ10PC (the tenth version of FREQ, developed for a PC). This particular version is also the only one of the three models reviewed that contains an interactive data input manager which greatly simplifies data entry and coding. Screens are displayed that

contain entry descriptions and entry blanks. The user simply fills in the blanks next to the description when prompted.

FREQ Input

As noted before, FREQ is a very versatile model and may be used for several applications, with model input determined by application. The input required for a "simulation only" (no optimization) run is summarized below.

The freeway is divided into subsections which can be considered as discrete homogeneous segments in terms of geometry, volume and capacity. Each subsection has a length, number of lanes, grade, capacity, design speed, volumes, percent trucks, ramp configuration and ramp capacity. Volumes that are needed include the mainlane volume entering the first subsection, the mainlane volume leaving the last subsection and all entrance and exit ramps within the study section. Once the volume data is entered, a synthetic origin-destination subroutine within FREQ determines turn percentages and thus trip length. Additional data is required if diversion of freeway traffic to a parallel route (frontage road) is added to the simulation run (parallel route's capacity). Additional options that may be invoked include a merging analysis determined by geometry (Highway Capacity Manual (2) method) and a weaving analysis (also Highway Capacity Manual method).

FREQ Output

Various levels of output may be obtained from the execution of FREQ. Output or optional output from a "simulation only" may include the following: Freeway and arterial design features (geometrics, capacity, and percent trucks on each subsection), distribution of vehicle occupancy by subsection, freeway performance tables by subsection (number of lanes, length, demand volume, serviced volume, capacity, weave efficiency, storage rate, v/c ratio, speed and emission data), freeway travel time, ramp/freeway delay, total travel time, total travel distance, contour maps of speed, density, queuing diagram, volume to capacity, fuel consumption, hydrocarbon emissions, carbon monoxide emissions, nitrous emissions and noise levels. If simulation and optimization are both chosen, the output will contain a ramp

10

metering plan summary table that includes on-ramp volumes, capacity and maximum and minimum metering rates, and then a set of simulation output based on the optimal timing plan.

<u>Difficulties</u>

Areas that present some difficulties for the novice user of the FREQ10PC model includes:

o   A basic simulation (base case, no priority entry or priority lane) of a freeway section may be conducted using FREQ10PC, however, this option is not listed in the first screen requiring user input. The user must know that such a simulation may be accomplished from the execution of either a FREQ10PE or FREQ10PL run.

o   As stated in one of the introductory screen, FREQ10 is very sensitive to capacity and demand input, and calibration of existing conditions is required for reasonable results. Calibration is the term used to describe the procedure of making the operational results from the simulation reflect real-world characteristics. FREQ10 is calibrated by adjusting segment capacities or the speed-flow relationship.

o   The option of the "Weaving Analysis" is not explained in the data input screens, and can affect the simulated results. The weaving analysis is performed in accordance with the 1965 HCM. The model considers only simple and two-part compound weaving.

o   The option of a "Merging Analysis" is also not explained in the data entry screens. The merging option allows the user to choose between a forced merge for entering ramp traffic (merge analysis off) or a merge analysis determined by volume and geometry (merge analysis on). The forced merge option allows entering ramp traffic to be introduced at the gore and immediately merged. If the merging analysis is turned on, FREQ10 uses the 1965 HCM procedures

11

for calculating demand at the merge point. If the demand exceeds 2000 vph in lane 1, a queue will form. The queue of vehicles will develop at the on-ramp if the volume at lane 1 is dominant; a queue will be generated on the mainlanes if the volume of the on-ramp is dominant. Volumes in excess of 2000 vphpl are commonplace in Texas urban area, and previous studies have shown that FREQ10 simulations calibrate more closely to actual conditions when the merging option is turned off (forced merge).

o   When entering data on any of the input screens, if the users makes a mistake, he must finish the screen and then enter it again to correct the mistake. The user cannot simply use the arrow or backspace keys to position the cursor where needed.

Application

The FREQ simulation model may be used on a uni-directional freeway section to evaluate such scenarios as lane additions, lane blockages (construction) and various ramp configurations. One of the highlights of FREQ is its ability to generate, evaluate and select an on-ramp metering scheme that will optimize freeway operations based on a user specified objective function. The objective functions that may be optimized include: maximizing vehicle input, vehicle-miles of travel, passenger input, and passenger-miles of travel. This particular version of FREQ will also allow the user to establish priority entry levels of passengers for exclusion from ramp metering. For example, vehicles with three or more passengers may be allowed to enter the freeway at a metered ramp without being controlled by the ramp meter (the ramp must contain at least two lanes).

The model allows vehicles queued on the on ramp to divert to a parallel alternative (frontage road) and enter the freeway on the next downstream on ramp. Some versions also allow for evaluation of lanes reserved for high occupancy vehicles such as carpools and buses.

FREFLO

The FREFLO model was developed by Payne in 1977 (2) and is a successor to the MACK II model. The FREFLO model was designed to evaluate incidents and model on ramp operations, and to provide standard measures of travel. The measures that are produced include flow rate, density, space mean speed, and travel time. FREFLO is a macroscopic, deterministic model that consists of a set of conservation and dynamic speed-density equations.

The present version of FREFLO has two significant extensions beyond the earlier MACK model: 1) freeway to freeway connectors, involving merge and diverge points, can be simulated and 2) buses, carpools, autos and trucks are distinguished by vehicle type. FREFLO may be used to simulate simple freeway operations or freeways with special purpose lanes (lanes that can be designated for use by buses and/or carpools only).

FREFLO is designed to be executed on a main-frame computer, but has been converted, but not released as a "stand a lone" program, by KLD and JHT Associates for FHWA into a PC version. FREFLO's incorporation into the CORFLO package for PC's is discussed in a later section.

FREFLO Input

Input into FREFLO is a tedious process, the geometrics, turning movements and volumes must be in an 80-column format in which each entry has a specific column and row order. A data input manager (similar to that in FREQ) does not exist for FREFLO, therefore the input data file must be constructed using a line/page editor or a word processor. The physical environment of a freeway is represented in FREFLO as a network of links and nodes. The links of the network generally represent freeway sections. The nodes of the network generally represent points where a physical change, such as a lane drop, change in grade or a ramp junction occurs. Similar to FREQ, FREFLO requires length of each link (subsection), number of lanes, capacity, free flow speed and entering volumes. The user may enter a custom speed-density relationship or use one of the default relationships

contained within the model. FREFLO vehicle trajectories are derived from user entered percentages of vehicles turning left, right or continuing through at each node. The data entry process is one of the few weaknesses associated with FREFLO.

FREFLO Output

One advantage that FREFLO has over FREQ is that FREFLO output contains a density for each link contained in the simulation. Since the introduction of the 1985 Highway Capacity Manual, freeway operations have been evaluated quantitatively by density and qualitatively by level of service. Density may be converted directly to level of service by simply using the table on page 3-8 of the 1985 HCM. Also contained in the FREFLO output are link volume and speed for each time period of simulation. Density, speed and volumes are reported individually for auto/trucks, buses and car pools. Cumulative freeway statistics for each link are also presented, these include: vehicle trips, vehicle miles, vehicle minutes, vehicle average speed, person trips, person miles and person minutes.

Difficulties

Areas in which difficulties were noted with the FREFLO simulation model are listed below.

o   There is no data input manager supplied with the FREFLO program, a text editor must be utilized and the user's manual must be tediously consulted.

o   Like FREQ10, the FREFLO program is very sensitive to the capacity input. Segment capacities and equilibrium speed-density relationships are used to calibrate FREFLO. FREFLO only has two speed-density curves from which to choose, but the program allows the input of coefficients for the equation of a user supplied curve. Density is much more difficult to measure directly, and so the speed-density curves are a more difficult concept to work with.

o   Unlike FREQ10, a graphical representation of the freeway network is not available with the FREFLO model, which makes checking for coding errors somewhat difficult.

14

Application

The FREFLO model may be used to simulate uni-directional or bi-directional freeway sections, freeway to freeway connectors, interchanges or complete freeway networks. FREFLO is not capable of generating a ramp metering plan (optimization) or modelling on-ramp diversion; it is simply a simulation program. FREFLO may be used to evaluate freeway operations resulting from lane additions, lane blockages, alternative ramp configurations or changes in demand.

INTRAS

INTRAS, which stands for INtegrated TRAffic Simulation, was developed by KLD in 1974 (3). INTRAS is a stochastic, microscopic model especially developed for studying freeway incidents. Stochastic models yield outcomes that are not completely predictable for a given set of inputs because they depend upon one or more random variables whose values vary among runs. Microscopic models treat each vehicle as a separate unit. INTRAS is a very sophisticated vehicle specific, time stepping simulation. INTRAS contains several algorithms which mathematically execute complex behavior including car following, lane-changing, and crash avoidance maneuvers. A detailed evaluation of complicated and unusual traffic operations (such as a weaving area or an incident) of a freeway section or even an entire surrounding roadway network can be simulated. INTRAS is capable of producing an on-ramp metering scheme (optimization), simulating an incident, simulating on-freeway diversion to an alternative route, and producing surveillance detector output.

The geometric representation of the roadway system in the INTRAS simulation model is accomplished by constructing a network of links and nodes, just as in FREFLO. However, since INTRAS may be used to simulate an entire roadway network or system, links are defined as freeways, ramps or surface streets. The INTRAS module used to simulate surface street operations (including sign and signal control) was adapted from the UTCS-1 simulation (the same as in the NETSIM model). INTRAS requires that the user input the percentages or flow rates that turn right, left or continue through node to produce its vehicle trajectories.

15

INTRAS is a very large program and is currently only available for execution on mainframe computers. The large quantities of input data required along with the large amounts of computing time required to maintain the individual vehicles in memory limits the widespread use of INTRAS.

INTRAS Input

As in FREFLO, INTRAS requires that data be coded into an 80-column format file, with each entry in a specific column and in a certain order. No data input manager exists for INTRAS, so the input data file must be constructed using a text editor or wordprocessor. Due to the immense amount of data that may be necessary to execute an INTRAS simulation, the input has been divided into required and optional. Table 1 lists the input data required to produce a simulation of a simple freeway section simulation (no ramp metering, no diversion, no incidents and no surveillance output). Table 1 also lists the embedded data that may be changed by the user to calibrate the model for specific applications. Origin and destination matracies are randomly developed by INTRAS using user input turning percentages at each node.

Table 1. Input data for INTRAS Model.

Required Input Data	Optional Input Data	Embedded Data
simulation duration time	curvature	probability of lead vehicle jumping at
link length	superelevation	the beginning of the green phase
link type	pavement type	speed of left turning vehicles
free flow speed	surface street	speed of right turning vehicles
grade	mean queue discharge headway	maximum jerk for vehicle type 1
number of through lanes	turn pocket sizes	car length by vehicle types
exit reaction location	fixed time signal control codes	acceptable gap for stop sign traffic
type and length of auxiliary lanes	traffic actuated signal control codes	acceptable deceleration rates for
lane number to which the auxiliary	background cycle length	driver types
lanes are connected	ramp metering initiation time	maximum deceleration for vehicle
lane number to which the ramp	type of ramp metering	types
lanes are connected	metering headway	acceptable gaps for unprotected left
ramp mean queue discharge	detector position	turning traffic
headway	speed threshold for metering	percentage of mean speed by driver
percentage of vehicles turning each	acceptable gap for metering	type
direction at each node	diversion initiation time	sensitivity factor for driver type
type of sign control at on-ramp	percentage of traffic to be diverted	startup lost time of queued vehicles
junction with mainlanes	nodes defining alternative paths for	limiting speeds by vehicle type for
flow rates for ramps and mainlane	diversion	grades
entrance	surveillance detector type	vehicle acceleration profiles for
percentage of flow rates for each	length and position of detectors	vehicle types
vehicle type	distance between loops	lane mean speed percentage
percentage of vehicles assigned to	incident code by lane	pavement friction coefficients
each lane	length of affected area	
	duration of incident	
	rubbernecking factor	

INTRAS Output

The INTRAS model produces many standard and optional output formats. The following describes a majority of the output formats. Summary tables of input parameters are provided for each simulation run. **Freeway link statistics** include: vehicles input and output, number of lane changes, current content, average content, vehicle miles, vehicle minutes, moving time, delay time, volume, speed and density. **Ramp and surface street link statistics** that are output include: vehicles input, vehicles output, current content, vehicle miles, vehicle minutes, speed, moving time, delay time, vehicle minutes/vehicle mile for total and delay, percent queue delay, average saturation percentage and cycle failures. **Surveillance data for each detector** by lane includes: mean speed, mean headway, percent of traffic at or below indicated speed and percent of traffic at or below indicated headway. The fuel consumption and emissions report contains (by link) gallons of fuel consumed by vehicle type, miles/gallon by vehicle type, HC by vehicle type, CO by vehicle type and NOx by vehicle type. Digital plots of vehicle time-space trajectories and contour maps of user specified MOE values may also be included in the output. Finally, output may also be generated containing simple comparisons and statistical tests of MOE values from separate simulation runs.

Difficulties

INTRAS is a microscopic model that requires more inputs than any of the previously described models, and as such presents many more difficulties for the user.

- o INTRAS does not have a data input manager, a text editor or equivalent must used to create the input file and to view the output file. Great care must be taken to code the appropriate values into the input data file due to the numerous inputs in each 80 character row.

- o Precise geometrics are necessary in coding the input file, including lane alignment information, curvature and grade. The lane alignment data is the most confusing section of the INTRAS model because each freeway link must be described by

18

connecting ramps and lanes, including auxiliary lanes, and no graphical representation of the simulation network is provided.

o Intras does not use a freeway segment capacity, instead it uses a "Mean Driver Sensitivity", which is similar to a mean time headway between vehicles. The use of such an input, along with the many other input variables, makes it difficult and time-consuming to calibrate the INTRAS simulation model.

o Mainframe computer programs, like INTRAS, are cumbersome to use, costly, and will not be widely accepted until a PC version is available.

Application

The INTRAS model is a highly complex system containing procedures for diagnostic testing, microscopic traffic simulation, output reporting, statistical analysis, detector output processing and digital plotting. Due to the large complex programming that INTRAS requires, storage limitations may limit its usage to small applications. To achieve meaningful results it may be necessary to segment the study freeway. Some of the applications for which INTRAS may be utilized are summarized below.

Freeway Geometric Features The INTRAS model may be used to simulate basic freeway sections, freeway to freeway connectors, ramps, connecting surface street operation or an entire urban network. Possible simulation applications include: lane additions and removals, ramp reconfigurations and changes in curvature or grade. Weaving sections may also be analyzed in detail due to INTRAS treating each vehicle as a separate unit.

Incident Simulation Capability A comprehensive freeway incident simulation procedure is included in INTRAS. The user may specify either lane blockages or "rubbernecking" to occur on a lane specific basis. Each incident may occur at any position along a freeway link for any given length of time. The severity of an incident may be changed with time. For example, it is possible to specify a two-lane blockage for some specified time period, after which the blockage may only involve one lane.

19

Surveillance System Simulation   INTRAS is capable of simulating "real world" information gathering (surveillance devices). The three types of surveillance traffic detectors that INTRAS can simulate include Doppler radar detectors, short inductance loops and coupled short inductance loops. Surveillance output, which depends upon the type of detector used, includes speed and time of actuation for each simulated vehicle, by detector.

On-Ramp Controls INTRAS contains four algorithm modules for simulating entrance metering. Clock time activated fixed metering, demand capacity metering, speed control metering or gap acceptance metering may be simulated at each on-ramp. All but the clock time activated fixed metering techniques require the use of mainlane and ramp detectors.

On-Freeway Diversion   INTRAS contains two procedures for diverting freeway vehicles to parallel service facilities. Clock time diversion and least time path diversion are the two methods allowed in the program. The user, however, must enter the alternative path for the latter diversion technique.

CORFLO

CORFLO is a name given to the combination of the PC versions of the FREFLO, NETFLO Levels 1 and 2 and TRAFFIC macroscopic programs . CORFLO may be used to simulate freeways, ramps, frontage roads and the surrounding urban street system. Although FREFLO and NETFLO Levels 1 and 2 have been available for several years, not until just recently has FHWA combined them into a PC version for freeway corridor analysis. FREFLO is used to model the freeway portion (the specifics of which were described earlier) and NETFLO Level 1 or 2 is used to model the urban links of the network.

NETFLO Levels 1 and 2 are event based, urban traffic simulation models, that vary in detail depending on the desired output. NETFLO Level 1 simulates each vehicle on the network as an individual entity, with driver and vehicle properties represented in a stochastic manner. However, it is not a time-scanning model, as is INTRAS where vehicles are moved each second according to car-following logic. Vehicles are moved as far downstream as possible in a single jump and specific vehicle trajectories are not generated. It produces similar

MOE output as the urban portion of INTRAS, with far fewer requirements for computer resources.

NETFLO Level 2 is adapted from the TRANSYT flow model. The traffic stream is described in terms of link specific statistical flow histograms that represent the platoon structure of traffic. The histograms used in Level 2 include the entry, input, service, queue and output histograms.

CORFLO Input
The input data file format for a CORFLO freeway simulation is identical to that previously described for FREFLO. Unlike the stand-alone FREFLO model, the CORFLO package includes a data input manager. The input manager is called TRAFEdit and has two components, Smart and Quick Edit. Smart Edit is a good tool for the novice user since it shows the various card groups that are required, the specific columns requiring input are highlighted and as the cursor is positioned in the various columns a user's manual type description of that entry is displayed. The Quick Edit component acts much the same as a wordprocessor or text editor. The entry locations by column are not shown or described and is to be used only by the experienced user.

Just as in FREFLO, user input turn percentages are used to produce the orign-destination information used by CORFLO. However, CORFLO is unique in that it is packaged with a traffic assignment model that can be used to produce a trip table if ramp volumes or turn percentages are unknown (i.e. freeway incident travel patterns).

CORFLO Output
Output from the freeway section of the CORFLO model is identical to the FREFLO model, described previously. Cumulative vehicle speed and density is produced for the freeway links (FREFLO). Level 2 MOE output is similar to that of Level 1 and INTRAS, yet not as detailed. Cumulative turning volumes and queues by lane are produced for each urban link.

Difficulties

The CORFLO package is a collection of previously developed simulation models, which includes the FREFLO model. The difficulties cited previously for FREFLO, in general, carryover for the CORFLO package. However, CORFLO does have a data input program.

o The order of execution of the various menu options is not clearly explained and novice users will probably stumble through the data input and execution options initially.

o The Quick Edit input option is nothing more that a program provided text editor and does not provide any helpful information on the location or range of inputs.

Application

The CORFLO package was designed to enable the user to simulate an entire urban network with a single model. CORFLO (FREFLO) may be used to simulate uni-directional or bi-directional freeway sections, freeway to freeway connectors, interchanges or complete freeway networks. CORFLO (NETFLO Level 1 and NETFLO Level 2) can also be used to simulate the urban links connected to the freeway (i.e. frontage roads and arterial streets).

FUTURE MODEL

One model that has recently been developed and is undergoing testing before release is the FRESIM simulation package.

FRESIM

The freeway simulation model that appears to be the most promising for future widespread application is FRESIM. FRESIM is a yet to be released microscopic, PC version, freeway corridor simulation model. The preliminary documentation indicates that FRESIM is an enhanced, more user-friendly, PC version of INTRAS, with all of its capabilities. FRESIM

was developed by JFT Associates and has just recently been released to test agencies. Testing will end early in March 1993, and widespread distribution will be sometime later.

FRESIM is a rather large fortran program and requires the use of extended memory on a PC. A 386 PC with a high clock speed (25 mhz or higher) is also recommended. Even with the recommended hardware, FRESIM will require longer computational times than any of the other freeway simulation models.

The FRESIM model is a considerably enhanced and reprogrammed version of its predecessor, the INTRAS model. The enhancements include improvements to both the geometric representation as well as the operational capabilities of the INTRAS model. Thus, FRESIM is able to simulate more complex freeway geometrics and provides a more realistic representation of the traffic behavior than INTRAS. These enhancements have also resulted in a more flexible and user-friendly model than INTRAS (4). FRESIM is capable of simulating freeway mainlanes, ramps, freeway to freeway connectors, variations in grade, curvature and superelevation, lane additions or drops, lane blockages and acceleration or deceleration auxiliary lanes. The input is nearly identical to that of INTRAS with the exception of the location of nodes and the use of a mean queue discharge headway for defining link capacity. The FRESIM output also mirrors that of INTRAS with the only difference being the link order of the output.

MODEL SUMMARY

Table 2 summarizes the major attributes of the models reviewed. Table 3 lists some of the situations for which each model may be used. Some of the advantages and disadvantages of using each model are listed in Table 4.

Table 2. Summary of Freeway Computer Programs

Model	Characteristics[a]				Microcomputer Version
	Traffic Stream	Basis	Objective	Randomness	
HCS	Macroscopic	Empirical	Simulation	Deterministic	Yes
FREQ	Macroscopic	Analytical	Simulation or Optimization	Deterministic	Yes
FREFLO/ CORFLO	Macroscopic	Analytical	Simulation	Deterministic	Yes
INTRAS	Microscopic	Analytical	Simulation or Optimization	Stochastic	No
FRESIM	Microscopic	Analytical	Simulation or Optimization	Stochastic	Yes

[a] A previous section includes discussions on the various characteristics.

Table 3. Features of Freeway Corridor Simulation Models

FEATURES	HCS	FREQ	FREFLO/ CORFLO	INTRAS	FRESIM
Permanent Lane Closures, Ramp Closures, or Lane Drops	Yes	Yes	Yes	Yes	Yes
Reduced Lane/Shoulder Widths	Yes	Limited*	Limited*	Limited*	Limited*
Changes in Geometrics (Ramp/Freeway Alignment)	Yes	Yes	Yes	Yes	Yes
Ramp Metering	No	Yes	No	Yes	Yes
HOV (Priority) Lanes	No	Yes	Yes	No	No
Temporary Lane Closures, Ramp Closures, or Incidents	Yes	Yes	Yes	Yes	Yes
Surveillance and Control Data	No	No	No	Yes	Yes
Diversion (Traffic Reassignment)	No	Limited	No	Limited	Limited
Freeway to Freeway Connectors	No	No	Yes	Yes	Yes
Multiple Time Periods	No	Yes	Yes	Yes	Yes

* Link capacity may be adjusted

25

Table 4. Advantages and Disadvantages of Freeway Corridor Simulation Models

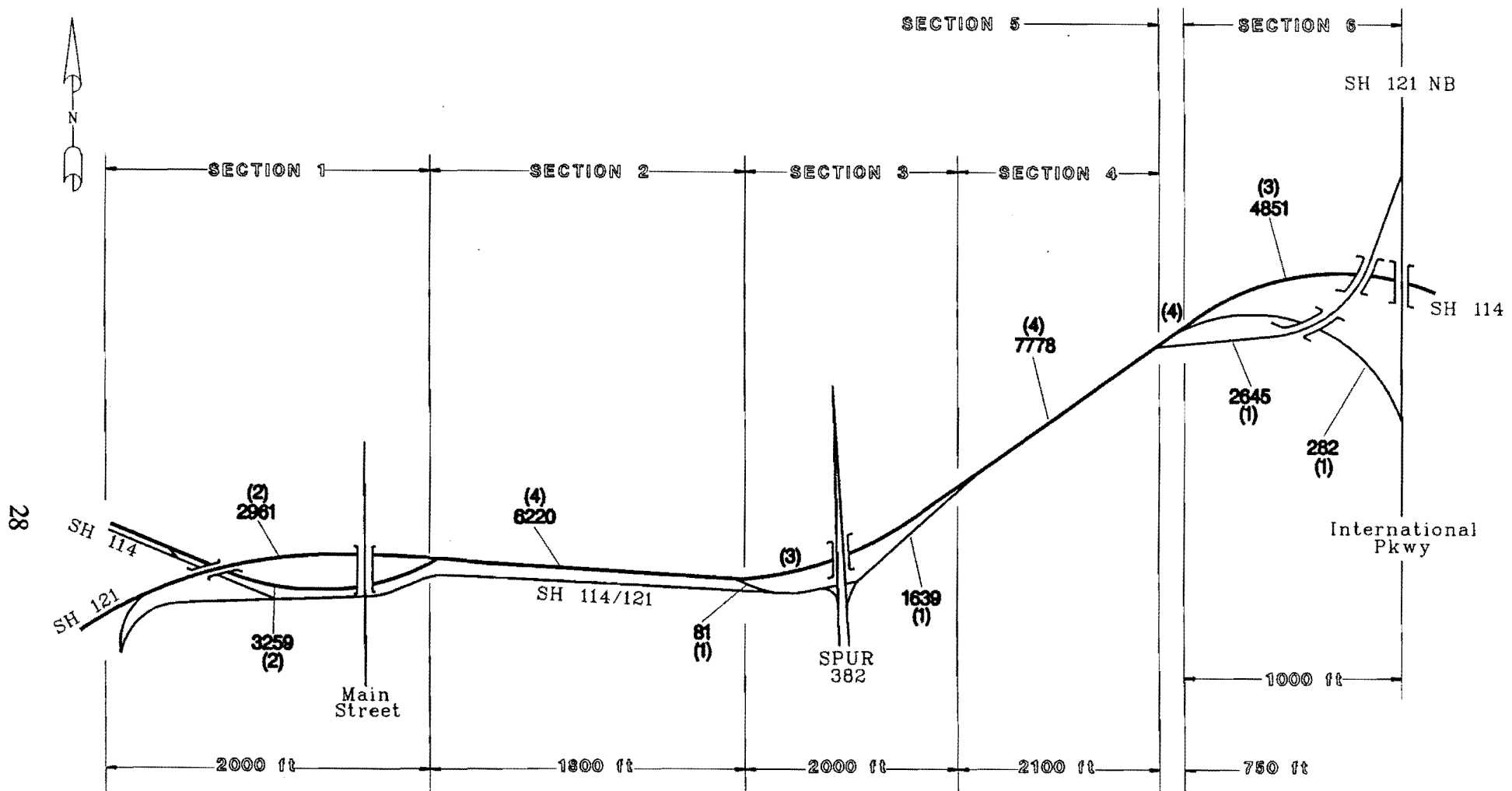| Advantages				
HCS	**FREQ**	**FREFLO/CORFLO**	**INTRAS**	**FRESIM**
Widely accepted Easy to use Microcomputer Version	Easiest of the Reviewed Models to Use Optimization of Ramp Metering Considerable Testing, Validation, and Use Nationwide Microcomputer Version Available User Friendly Data Input Manager	Explicit Treatment of Freeway System Can Evaluate Temporary Changes in Roadway Characteristics Compatible with TRAFFIC, an equilibrium traffic assignment model Can Simulate Freeway to Freeway Connectors Produces Density as output MOE CORFLO is developed for use on a microcomputer	Explicit Treatment of Freeway and Surface Street System Can Evaluate Temporary Changes in Roadway Characteristics Can Evaluate Complex Weaving Sections Can Simulate Freeway to Freeway Connectors Can Evaluate Geometric Changes and Vehicle/Driver Characteristics	Explicit Treatment of Freeway Surface Street System Can Evaluate Temporary Changes in Roadway Characteristics Can Evaluate Complex Weaving Sections Can Simulate Freeway to Freeway Connectors Can Evaluate Geometric Changes and Vehicle/Driver Characteristics Microcomputer Version
Disadvantages				
Empirically based no systemwide analysis capabilities	Only 1 Directional Freeway Segment Can Be Evaluated Only 1 Simplified Parallel Alternative Route Can Be Modelled Cannot Simulate Freeway to Freeway Connectors	Difficult Data Entry (No Data Input Manager for Mainframe FREFLO)	No Data Input Manager Extensive Input Data Required Requires Mainframe Computer Long CPU Times Required	No Data Input Manager Extensive Input Data Required FRESIM not currently available to public

26

CASE STUDY COMPARISON OF THE MODELS

As a means of demonstrating the performance of each model presented in this report, a case study of an actual freeway segment was selected. Figure 1 presents the lane configuration and existing AM peak hour volumes along the study segment. Prior to the merge, both S.H. 114 and S.H. 121 are four-lane freeways, two lanes in each direction. Traveling east, the two lanes from each freeway merge into a four lane section. The next exit to SPUR 382 results in a lane drop with only three lanes continuing through the interchange, but a lane addition from the succeeding SPUR 382 entrance returns the freeway to four lanes. The four lanes are continued past the exit to S.H. 121 northbound until the exit to Dallas/Ft. Worth Airport. There is a lane drop at this exit and three lanes continue past the boundary of the study area.

Manual volume counts were conducted for the upstream mainlanes of S.H. 114 and S.H. 121 and machine counts were taken at all of the ramps throughout the study segment. Average travel speeds along the freeway were measured using the floating car method and license plate matching was used to determine the freeway origin and destination of the vehicles in the two weaving sections. The first weaving section is between the merge of S.H. 114 and S.H. 121 and the Spur 382 exit. The second weaving section is between the entrance from Spur 382 and the exit to S.H. 121 northbound. Figure 2 shows the average speeds and areas of queueing that exist from field observations. All operatinal data was collected in April of 1988.

Each of the available simulation models were used to simulate the case study freeway segment for a single one hour time period (FREFLO,CORFLO, INTRAS, and FRESIM will simulate multiple time periods, but HCS is limited to only a single time period). The default values for each simulation were used and other variables were input to make the simulations as comparable as possible. A freeway mainlane capacity of 2000 vphpl was used throughout all of the simulations that required such an input.

Case Study Findings

A summary of the simulation speed and Level-of-Service output is shown in Tables 5 and 6 respectively. The results from HCS appear to produce reasonable LOS, however the calculated

Figure 1. Case Study Site Geometrics and Volumes

SECTION 5

SECTION 6

SH 121 NB

SECTION 1

SECTION 2

SECTION 3

SECTION 4

SH 114

N

29

SH 114

SH 121

SH 114/121

International
Pkwy

Main
Street

SPUR
382

17 mph

30 mph

42 mph

51 mph

LEGEND

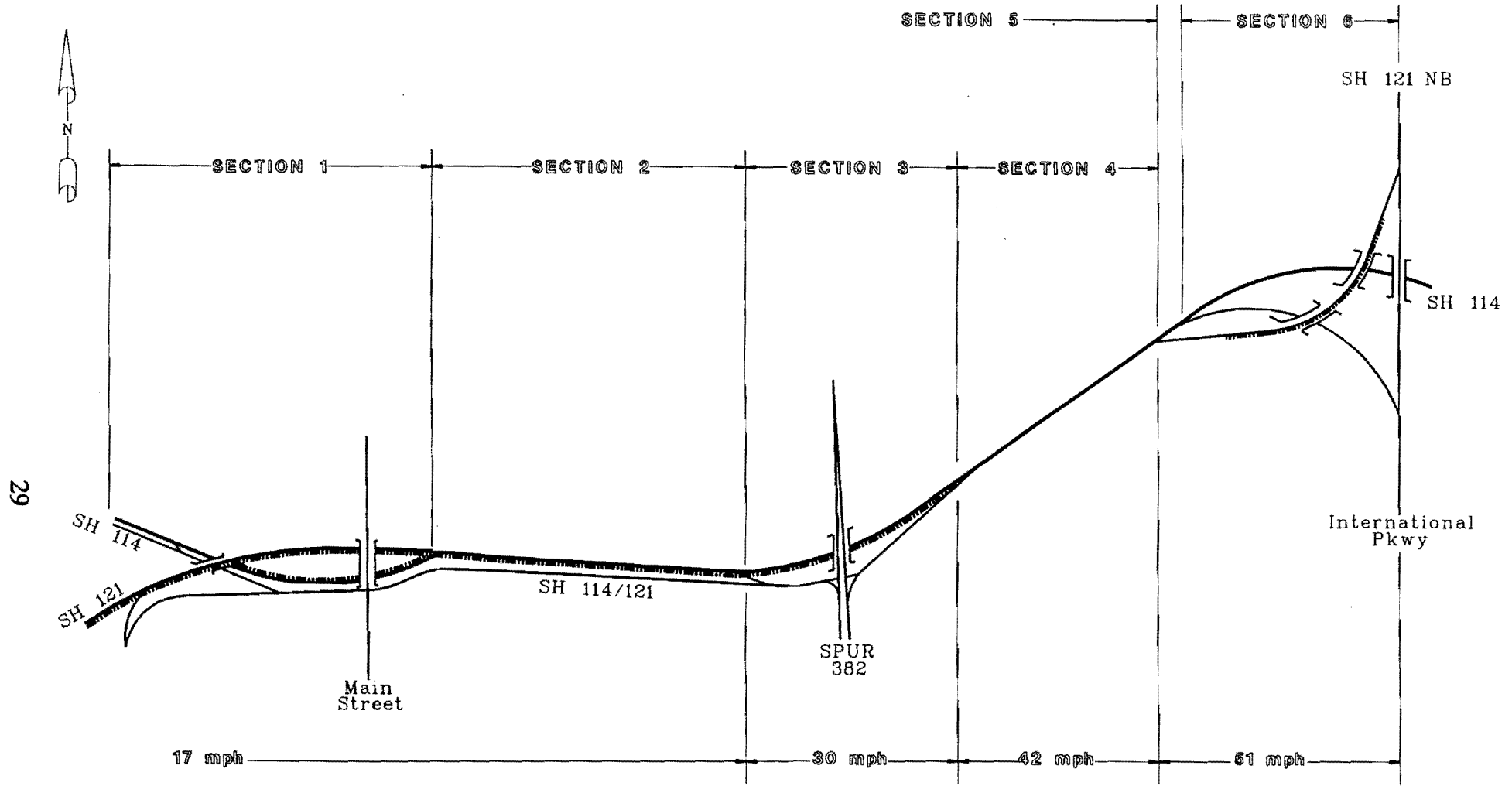XX- Speed in Miles per Hour
---- Queueing During AM Peak

Figure 2. Case Study Site Simulated Speeds

speeds are not very reasonable. This is due to HCS's use of the 1985 HCM speed flow curves that underestimate speeds for higher flow conditions (i.e. Sections 4-6). The use of HCS in this case study was tedious; six individual simulations (three basic freeway and three weaving area segments) were required to simulate this study site.

Table 5. Simulated Freeway Speeds for Case Study

Speed (mph)						
Section	1	2	3	4	5	6
Actual	17	17	30	42	51	51
HCS	51	*30	**	*35	43	44
FREQ	38	23	35	55	58	56
FREFLO	56	33	17	22	43	52
CORFLO	54	24	16	22	39	44
INTRAS	49	48	24	38	48	56

* Average of weaving and non-weaving vehicles
** Speed highly variable for LOS F

30

Table 6. Simulated Freeway Level-of-Service (LOS) for Case Study

LOS (Based on Density)						
Section	**1**	**2**	**3**	**4**	**5**	**6**
*Actual	F	F	F	F	D	D
HCS	D	F	F	E/F	E/F	E
FREQ	D	F	E	D	C/D	C/D
FREFLO	D	E	F	F	D	D
CORFLO	D	F	F	F	D	D
INTRAS	D	D	E	F	D	D

* Actual LOS based on density, calculated from section speed and volume.

The FREQ and FREFLO simulation models replicated the observed conditions relatively well. The speeds across all the sections are not identical to the actual speeds, but they do however follow the general trend. As one would expect, FREFLO and CORFLO produce nearly identical results, CORFLO however produces slightly lower speeds across all sections. The lower speeds are possibly due to a different speed/density relationship being used in CORFLO. INTRAS, since it is microscopic in nature, should theoretically simulate weaving sections more accurately. INTRAS did produce good results in Sections 3-6, but overestimated the speeds and LOS in Sections 1 and 2. Again, it should be noted that the simulations conducted in this case study used most of the default values for variable inputs to provide a basis for comparison. In actual practice the user would use these variable inputs to "calibrate" the model to more precisely replicate actual conditions.

SUMMARY

This report has presented some considerations when approaching a project that may require computer simulation. Definitions of model attributes are given as well as a list of steps that should be followed before choosing a simulation model. An overview is presented of the input, output and application of the freeway simulation models that are available and upcoming. The models examined include HCS, FREQ, FREFLO, INTRAS, CORFLO and FRESIM. The origin and development of the models are reported as well as hardware requirements, input processing, and useful applications. Details are given as to the required data input, the optional data input, the standard output and the optional output.

The models reviewed in this report will all simulate traffic movement on a basic freeway segment. However, each model has its own unique requirements and capabilities. HCS is a well accepted macroscopic method of "spot checking" freeway operations. However, HCS is tedious to use and is not applicable when an entire freeway system is being evaluated. FREQ is a macroscopic model, executed on a PC, containing a user-friendly data input manager, designed to simulate uni-directional freeway segments. FREFLO is a macroscopic model, executed on a mainframe computer and is capable of simulating entire freeway networks in any direction. INTRAS is a microscopic, highly complex mainframe computer program that is capable of simulating entire freeway networks, including frontage roads and urban arterial streets, all in a single simulation. CORFLO is a PC version of the FREFLO model combined with NETFLO Levels 1 and 2 and can be used to model the freeway and surrounding surface streets macroscopically. FRESIM is a PC version of the INTRAS program with all of its capabilities.

This report may be used by the engineer or planner to help select the freeway simulation program which is appropriate for the application. The report also includes a generic methodology for conducting a freeway simulation evaluation of various alternatives. And finally, this report presents a case study to show potential users a comparison of each freeway simulation model.

RECOMMENDATIONS

Each model is capable of simulating a basic freeway segment, however each has strengths and weaknesses. Assuming computer hardware is not a limiting factor, Table 7 presents this study's recommended ranking of the preferred freeway simulation model for particular applications. FREQ is recommended more highly than the other models for uni-directional, HOV and ramp metering simulations based primarily on the ease of entering data with FREQ's user-friendly data input manager. FREFLO/CORFLO are recommended for freeway system applications, and FRESIM is recommended for the detailed analysis of the freeway operations. INTRAS is not recommended for use for any of the applications since the FRESIM model is just as capable and is more user friendly than INTRAS. FRESIM is also capable of being executed on a microcomputer.

Table 7. Recommended Ranking for Freeway Simulation Applications

Application	HCS	FREQ	FREFLO/ CORFLO	INTRAS	FRESIM
Uni-directional lane addition/drop	-	1	2	4	3
Uni-directional lane blockage	-	1	2	4	3
Uni-directional ramp reconfiguration	5	1	2	4	3
Freeway segment with HOV lane	-	1	2	-	-
Development of a ramp metering plan	-	1	-	3	2
Bi-directional lane addition/drop	-	-	1	3	2
Simulation of freeway to freeway connectors	-	-	1	3	2
Simulation of portions or entire freeway systems	-	-	1	3	2
Detailed analysis of weaving sections	3	-	-	2	1
Changes in grade, curvature or pavement	-	-	-	2	1
Changes in vehicle mix (classification)	5	4	3	2	1
Changes in driver behavior (aggressiveness)	-	-	-	2	1
Lane restrictions by vehicle type	-	-	-	2	1
Freeway segments with auxiliary lanes (full or partial)	-	-	-	2	1

1 = Most recommended, 2 = Next most recommended, etc., - = Not capable

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