TABLE 1 PASSER III LEVEL OF SERVICE CRITERIA FOR OPERATIONAL MEASURES OF EFFECTIVENESS AT SIGNALIZED DIAMOND INTERCHANGES

Measures of Effectiveness	Level-of-Service					
	A	B	C	D	E	F
Volume-to-Capacity Ratio[a]	<.60	<.70	<.80	<.85	<1.0	>1.0
Average Vehicular Delay[b]	<6.5	<19.5	<32.5	<52.0	<78.0	>78.0
Interior Storage Ratio[c]	<.05	<.10	<.30	<.50	<.80	>.80

[a] "Guide for Designing and Operating Signalized Intersections in Texas."
[b] Total delay (1.3 times stopped delay).
[c] Average queue length per cycle (veh) divided by the available queue storage (veh).

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INTERCHANGE OPERATIONS: SOFTWARE EVALUATION TECHNIQUES IN USE

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Introduction

Serving as the interface point between two intersecting facilities (freeway/freeway, freeway/arterial, or arterial/arterial), an interchange provides an environment that allows vehicles to perform weaving and merging maneuvers safely and smoothly when they move from one facility to another. Since the weaving/merging activities cause disturbance to the traffic flow, a poorly designed and/or operated interchange can easily become a traffic bottleneck. In spite of its importance, interchange planning and operational analysis have received much less attention than other components of the freeway system, judging from the methodologies and analysis models available. The formation of the Interchange Subcommittee under the Transportation Research Board Committee on Highway Capacity and Quality of Service is a first step in the right direction to address this issue and recognize the need for developing methodologies and modelling tools for analyzing the unique operating and performance characteristics of interchanges.

The objective of this paper is to review the existing software evaluation techniques for interchange operations analysis, to identify unique issues related to interchanges and their immediate operating environment, and to provide recommendations for future developments.

Interchange Analysis

The analysis of interchanges can be categorized into two types: planning/design analysis and operational analysis. Planning/design analysis is conducted when designing a new interchange or converting an existing interchange from one form to another. The analysis usually starts with the study of the warrant for a new interchange, followed by the selection of an appropriate interchange design from various alternatives. In general, the selection is based on at least the following considerations (*1,4*):

- Geometry: right-of-way, turning angle, open pavement area, street widths, drainage, lighting, etc.;
- Traffic Demand: on- and off-ramp traffic patterns;
- Safety: sight distance, clearance, allowable travel speed, traffic conflicts, etc.;
- Structures: bridge designs, span lengths, retaining walls; and
- Construction cost and user benefit, including environmental factors.

On the other hand, typical purposes of an operational analysis are to determine whether an existing interchange meets current or future traffic demand, and to improve its operation through signal optimization or minor geometric changes such as restriping to add a left-turn bay, etc. Unlike the planning/design analysis, the operational analysis is mainly concerned with traffic operations and capacity aspects of the interchange, which are also the focus of this paper.

Survey of Current Practice

To date, there are many computerized traffic models available for evaluating freeway or surface street networks. Since interchanges are composed of interconnecting freeway and/or surface street sections, current practice generally is to evaluate each component separately: freeway models for the freeway section, and surface street models for the cross street. There are some software models that can evaluate integrated systems consisting of both freeway and surface street networks. However, the purpose of these integrated models is to include the on-ramp and off-ramp traffic into consideration, not to examine the performance of the interchange itself. None of the models are designed especially to address the complex traffic signal timing and vehicular operations at interchanges, such as weaving/merging/diverging maneuvers.

As part of this study, a survey was conducted to get a glimpse of the type of software models that have been used in evaluating traffic operations at interchanges or intersections near freeway junctions. Questionnaires were sent to members of the TRB Freeway Operations Committee and of the new Interchange Subcommittee of the TRB Highway Capacity and Quality of Service Committee. Twenty-four (*24*) responses were received, the results of which are summarized in Figures 1 and 2.

Seven software models were listed in the questionnaire: HCS, PASSER-II, PASSER-III, TRAF-NETSIM, TEXAS, TRANSYT-7F, and INTRAS. All of which are developed either by the Federal Highway Administration or the states, though basic development of the TRANSYT model was by the British Transport and Road Research Laboratory. Each member was asked to select the models used for interchange analysis as well as the name of any other tools that they have used. Except for two members who have no experience with any software tool, all members specified more than one model. As can be concluded from Figure 1, popular software models such as TRANSYT, HCS, PASSER, and NETSIM are still the most frequently used tools in evaluating interchanges. The "Other" category covers those models that received less than three votes (i.e., INTRAS, FRESIM, FREQ, TEXAS, etc.)

In addition to specifying the models used, each member was also asked to identify the specific analysis that the models were applied to. The following ten areas of analysis were identified according to the survey data:

- capacity,
- interchange type,
- intersection spacing,
- progression,
- queue analysis,
- signal timing,
- spillback,
- ramp metering,
- weaving on cross roads, and
- weaving on freeways.

Figure 2 shows the number of members who selected each of these specific areas. Of these, capacity, weaving, and progression on surface streets appear to be the most popular areas of interest.

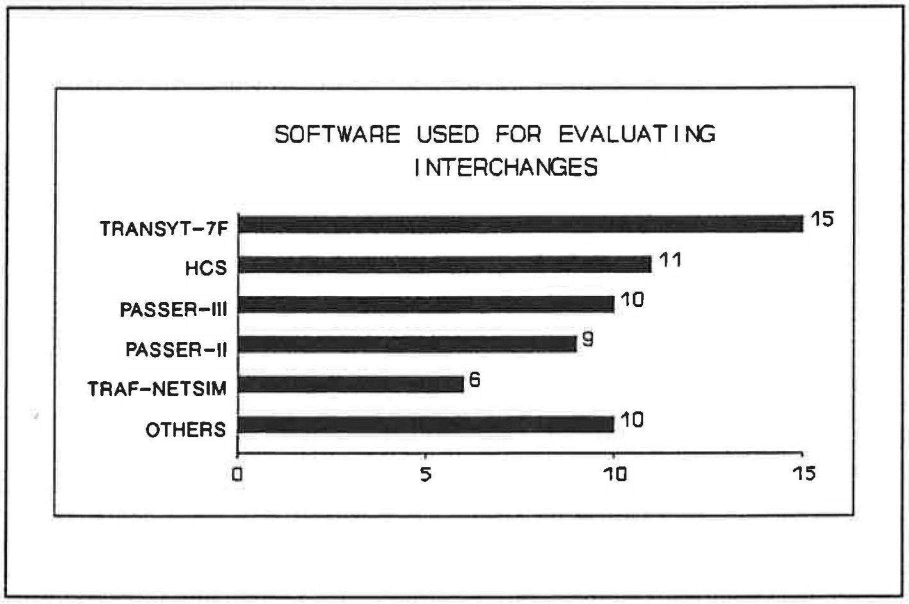

FIGURE 1 Software used for evaluating interchange performance.

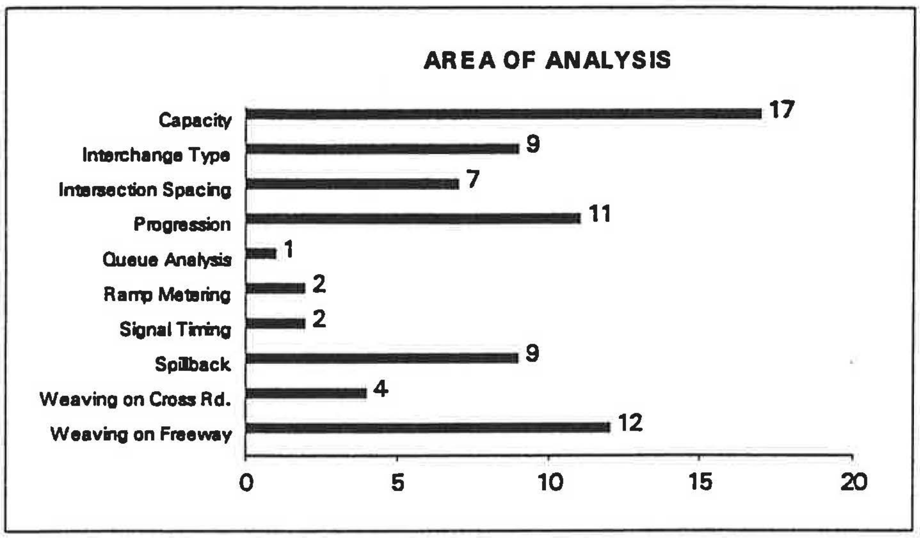

FIGURE 2 Area of analysis.

Software Requirements for Interchange Evaluation

In order to evaluate properly traffic performance at interchanges, the computerized model should be capable of dealing with the unique and complex characteristics. These major characteristics can be identified as:

1. *Weaving Maneuvers*: Complex and heavy weaving, merging, and diverging maneuvers are the unique characteristics of traffic operations at the interchange area. Regardless of the type of interchange, weaving occurs on the freeway when on-ramp vehicles try to merge into the mainline traffic or when freeway vehicles try to move to off-ramps. For clover and directional type interchanges, weaving occurs on the surface street when on- or off-ramp vehicles interact with surface street through traffic. Weaving on arterials to access crossing arterials can occur at all interchange types. The disturbance effect of these vehicular operations can significantly hamper capacity and safety on the surface street.

2. *Closely-Spaced Intersections at Diamond Interchanges and Vicinity*: The unbalanced traffic pattern caused by the lack of a through movement for both off-ramps, coupled with the short distance between the ramp/arterial intersections, results in a unique traffic operation that cannot be treated simply as a regular two-node surface street network. These two closely-spaced intersections require coordinated operation using a special three or four-phase signal timing plan, in order to achieve maximal throughput and ensure safety. Often adjacent intersections on the arterial are closely spaced as well near all interchange types, not just diamonds.

3. *Spillback*: Another critical design element for closely spaced interchange and arterial intersections is the vehicle storage capacity for the traffic movements on the arterial. Because of the close spacing, spillback can occur very easily if the signal timing plan is not compatible with the vehicle storage areas. Spillback disrupts traffic flows, degrades performance, and could easily cause gridlock along a significant portion of the network. Spillback can also occur onto the freeway as the result of excessive queues forming on off-ramps, or onto the arterial as the result of queues occurring on on-ramps due to their inability to enter the freeway.

4. *Ramp Metering*: In order to maintain smooth traffic flows on the freeway, many agencies have started implementing ramp metering control, both pretimed and actuated, on freeway on-ramps to regulate the surface traffic entering the freeway. The analysis software should be able to model this ramp metering control and address the effects of ramp metering on interchange performance.

Computer Models For Interchange Analysis

The main objective of this paper is to make the user aware of the availability of computer models which are suitable for analyzing traffic operations at interchanges. Use of these computer software tools will assist engineers in developing and evaluating alternative improvement scenarios at interchange areas.

Traffic analysis software currently being used by traffic engineers generally can be categorized according to the aspect of traffic operations with which they deal or the manner in which they model traffic operations: *analytical*, *optimization*, and *simulation*. It should be noted that these categories can overlap. A general review was performed to identify existing computer models that could be applied to interchange analysis either directly or indirectly. The review focused on public domain software models developed by the FHWA or the states. Those models identified are described below.

Analytical Models

Analytical models are the software implementations of analytical equations or procedures. The purpose of developing such models is to automate the analysis process, thus minimizing human errors and improving efficiency. The Highway Capacity Software (HCS), a computerized form of the standard 1985 *Highway Capacity Manual* (HCM; TRB Special Report 209), is the only model that fits into this category.

The HCS was developed in modules with each module corresponding to a chapter in the HCM. In addition to the signalized and unsignalized intersection analysis which can be applied to the ramp/arterial intersections, there are two modules which can be applied to interchange analysis: Chapter 4 for weaving areas, and Chapter 5 for ramps. The weaving analysis procedure was developed for freeways, but can be used with caution to approximate the effects of weaving on surface streets. The methodology relates the level of service in weaving areas to the average running speeds of weaving and non-weaving vehicles. The parameters used in the capacity analysis include total volumes, weaving volumes, length of weaving area, and total number of lanes at weaving areas.

For ramp capacity analysis, the methodology establishes the ramp capacity as a function of merge volume for on-ramps, diverge volume for off-ramps, freeway volume, and ramp configurations. The analysis also takes into consideration the upstream and downstream volumes and distance between ramps. Because ramps are analyzed independently of other highway components, the effects of spillback from ramps into freeways or surface streets can not be modelled by the HCS.

Optimization Models

Optimization models are used to determine the "best" signal timing plan for the *signalized* intersections in an urban network. In general, the models reach their decisions by achieving certain system objectives such as maximizing progression or minimizing delay. The signal timing plan is optimized by determining the best combination of timing parameters such as cycle length, split, offset, and phase sequence within the constraints of the optimization criteria (i.e., progression, delay, etc.). The networks that can be optimized include isolated intersection's, linear networks (arterial), and grid networks. Four optimization models, SOAP, TRANSYT-7F, PASSER-II, and PASSER-III are reviewed in this paper.

Signal Optimization Analysis Program (SOAP) is a signal optimization and evaluation program which determines optimal phasing and timing for any isolated intersection based on analytic formulas of operations. It also allows the user to analyze existing or pre-determined timing and to evaluate a wide range of intersection signal design alternatives. The intersection can be controlled by either a pretimed or an actuated controller. The input data required by SOAP include geometric configurations, signal timing data, traffic volumes, headway, and capacities. The program can also generate Measures of Effectiveness (MOE's) such as traffic delays, stops, fuel consumptions, and left-turn conflicts.

TRAffic Network StudY Tool (TRANSYT) 7F is a macroscopic network simulation and optimization model that represents traffic flows in the network as histograms over small time increments. It can determine signal timing (cycle, split and offset) for a coordinated network of up to 50 intersections, both signalized and unsignalized, based on a user defined "performance index" (typically a weighted sum of stops and delays). Traffic control is fixed-time, two to seven phases (including pedestrian movements) with fixed sequential phasing, though actuated operation can be approximated. Priority lanes may be designated for buses. A TRANSYT network is structured on a link-node basis. There are 23 input card types available to describe the network configurations, traffic data, signal timing, and parameters controlling the optimization process.

The major outputs produced by TRANSYT are:

- Performance table generated for each intersection and the entire network. The table shows link volumes, saturation flow, degree of saturation, total travel time, delay time, stops, fuel consumption, maximum back of queue, and green times;
- An optimized signal timing table with splits and offset;
- Flow profiles graphically showing the arrival and departure flow patterns; and
- Time-space diagrams and performance measures for any number of routes desired.

Progression Analysis and Signal System Evaluation Routine (PASSER) II is designed to determine optimum progression (maximum bandwidth) along an arterial street considering various multi-phase sequences. The program can handle arterials with up to twenty intersections. The signal timing parameters that can be optimized include cycle length, split, offset, phase sequence (for the arterial), and progression speed.

Basic inputs required by PASSER-II include turning volumes, saturation flow rates, and minimum green times for each movement at every intersection, distances between intersections, average link speed, queue clearance intervals, and permissible phasing sequence. The program produces optimum cycle length, bandwidth, average speed, and signal timing (phase sequence, split, offset), plus performance measures generated from analytic relationships (degree of saturation, delay, stops and fuel consumption). It also generates a time-space diagram showing the progression bands for both outbound and inbound directions, with optimum progression speed.

PASSER-III is an extended version of PASSER-II designed to assist traffic engineers in analyzing fixed-sequence signalized diamond interchanges, pretimed or actuated. Different phasing patterns are permitted including all combinations of "leading" and "lagging" greens, plus the commonly used "4-phase with overlap" pattern. The program is designed to evaluate the interchange performance under existing traffic and signal conditions or to optimize the interchange performance by calculating the best phase sequences, green splits, offsets, and cycle lengths. The effects of queue build-up between interchange intersections are considered explicitly. In addition, the program can evaluate the effectiveness of various geometric design alternatives, e.g., lane configurations, U-turn lanes, and channelization.

The data required for interchange analysis include geometric descriptions, desired phasing pattern(s), cycle length, overlap, queue capacities, movement volumes, and capacities. Outputs are optimal timing designs, similar MOE's as described in PASSER-II, and time-space diagrams.

Simulation Models

Simulation models provide a safe and cost-effective way to evaluate various traffic improvement scenarios before the actual implementation. In terms of design, simulation models can be macroscopic (which represent traffic in aggregate bunches or platoons), or microscopic (which process each vehicle individually). Microscopic models, though requiring more computing time and resources to run, can represent vehicles more realistically than the macroscopic models. Microscopic models theoretically are more responsive to different traffic strategies and can also produce more accurate MOE's and provide enough flexibility to test various combinations of supply and demand. Macroscopic models, on the other hand, often do not have the sensitivity and resolution required to study detailed traffic and geometric changes associated with interchange design. For example, it could be very difficult to use a macroscopic model to evaluate the spillback effect within a diamond interchange when the intersection spacing is reduced, say from 450' to 400'. In this paper, only the microscopic models will be reviewed.

Traffic EXperimental and Analytical Simulation (TEXAS) is designed to perform detailed evaluations of traffic performance at single, isolated intersections. Vehicle and driver characteristics are all treated stochastically in the program. The model is useful in evaluating the effects of roadway changes, changes in driver and vehicle characteristics, intersection control, lane channelization, and operational effects of signal timing plans. The latest version of TEXAS has been enhanced to include new features specifically for diamond interchange analysis.

The data requirements include detailed intersection geometrics, traffic patterns, volumes, signal timing, and vehicle and driver characteristics. The output includes intersection performance MOE's, vehicle interaction MOE's, and animated graphics files for reviewing simulation results pictorially.

TRAF-NETSIM is one of the component models in the TRAF system. NETSIM is an interval-scanning microscopic simulation model for surface street networks. The traffic stream is modelled explicitly according to car-following theory; each vehicle on the network is treated as an identifiable entity. This approach allows the program to simulate the detailed, vehicle-specific traffic processes so that most conditions experienced on an urban traffic environment can be realistically described. As far as microscopic traffic simulation, TRAF-NETSIM constitutes the state-of-the-art.

An extended version of TRAF-NETSIM currently is being developed for the FHWA. The objective is to include some of the latest developments in traffic signal controller functions and to expand the capabilities of the model such that vehicular movements within intersections and grade-separated interchanges can be simulated. A safety-related MOE, traffic conflicts, is being developed as well. Traffic conflicts occur when a vehicle is forced to take some action (alter its speed, trajectory) to avoid a collision with another vehicle. These new features should be helpful particularly in analyzing the weaving and merging of traffic at interchanges and will be able to simulate traffic operations for general types of interchanges ranging from simple underpass/overpass interchanges to complicated ones.

Two graphics postprocessors, ANETG and SNETG, which allow users to view the TRAF-NETSIM simulation results pictorially, are also being revised accordingly. The revised graphics software will allow traffic engineers to review and evaluate traffic performance within intersections and grade-separated interchanges through various graphics displays, both static and animated.

INtegrated TRAffic Simulation (INTRAS) is a vehicle-specific, interval scanning simulation program designed to represent realistically traffic and traffic control in a freeway and surrounding surface street environment. Although INTRAS has been developed mainly for use in studying freeway incident detection and control strategies, it is an ideal tool for studying urban corridors. The surface street model in INTRAS is patterned after the logic of an early version of the NETSIM simulation model (UTCS-1) and allows the user to study the interaction between surface streets with either other surface streets or freeway ramps. Provision is made for the modular inclusion and referencing of specially coded subroutines to model traffic responsive signal control. Ramp metering and freeway traffic diversion procedures are also included.

INTRAS is being enhanced currently by FHWA to allow the model to change the signal timing plans and/or the ramp metering rates between sub-intervals and to add the capability of simulating areawide traffic-responsive ramp metering schemes, with or without queue override features. With these new features, users will be able to evaluate traffic performance at interchanges, both isolated and integrated, by simulating a variety of traffic operations and signal coordination strategies.

Summary of Software Capabilities

The capabilities of the eight models reviewed above are summarized in Table 1 in terms of the analysis areas to which they can be applied.

Except for "*Interchange Selection*," which is a critical element in the planning/design analysis, and perhaps "*Intersection Spacing*," analysis areas identified in the table are components of the operational analysis. In other words, most of the capabilities offered by the existing software models are geared to operational analysis rather than planning/design analysis. The following areas deserve further discussion.

Interchange Selection

In their current form, the application of software models in this area is limited to evaluating the traffic operation

TABLE 1 SOFTWARE MODEL CAPABILITIES

	HCS	SOAP	T7F[1]	PSR-2[2]	PSR-3[3]	TEXAS	NETSIM[4]	INTRAS
Ramp Capacity Analysis	X							
Interchange Selection			X			X	X	
Intersection Spacing			X	X	X	X	X	X
Progression				X	X			
Ramp Metering								X
Signal Timing Optimization		X	X	X	X			
Queue Analysis			X		X	X	X	X
Spillback			X		X	X	X	X
Weaving on Crossroads	X						X	
Weaving on Freeways	X							

Note: [1]TRANSYT-7F [2]PASSER-II [3]PASSER-III [4]TRAF-NETSIM

aspects of various interchange designs. None of the models are comprehensive enough to evaluate geometric properties such as sight distance, right-of-way or cost. Because TRAF-NETSIM, TRANSYT-7F, PASSER II and SOAP can generate fuel statistics, their output can be used to quantify user benefits when conducting benefit-cost analysis. TRAF-NETSIM also can provide emission statistics.

Considerable care should be taken when selecting appropriate software models to determine the type of interchange most applicable to the conditions being studied. For example, Leisch, et al. (*2*), compared the operational characteristics between two interchange forms: the single-point urban interchange (SPUI), and compressed diamond interchange (CDI) using TRANSYT-7F. The results showed that CDI's are more efficient than the SPUI's except for the case when both left turns on the cross streets are heavy and balanced. However, the CDI received a much less enthusiastic endorsement from one recent study. One reason could be that queues in the TRANSYT-7F model are "vertical." That is, the adverse effects of spillback from left-turn bays or from short through lanes within the interchange area are not represented properly by TRANSYT-7F in terms of, for instance, effects on upstream saturation flow rates. On the other hand, microscopic simulation models such as TRAF-NETSIM normally have car-following behavior algorithms built in that will decrease the upstream saturation flow rate in recognition of standing or slow moving downstream queues.

Ramp Metering

The capability of modelling ramp metering control is important when studying spillback from the ramps onto the surface street system. Even though INTRAS is the only model that currently has this feature, FHWA is integrating NETSIM and FRESIM, a microscopic freeway simulation model in the TRAF family, to give users this capability in a much more realistic fashion.

Weaving on Crossroads

Both the HCS and TRAF-NETSIM can be used to analyze the weaving behavior on the crossroad in a limited way. The HCS has a chapter on freeway weaving which can be extended to weaving analysis on crossroads. However, further study is needed to determine the appropriateness of this application. TRAF-NETSIM can simulate weaving, to some extent, by treating the weaving points as yield sign-controlled intersections. The extended version of TRAF-NETSIM that FHWA is developing currently will have weaving modelling built in; this new version will treat the interchange area as an integrated area. In addition to modelling traffic interactions, the model will allow users to specify the origin-destination pattern for every traffic movement through the area, such that the amount of weaving should be represented reasonably. The ability to simulate an interchange with graphic display capabilities should make the new TRAF-NETSIM a comprehensive model.

Summary/Recommendations

Existing software evaluation techniques for interchange operations analysis were reviewed and summarized in this paper. The results of a survey were also reported. There is no doubt that interchange analysis is important, yet the availability of good computerized models is limited; features offered by existing models are confined to certain analysis areas.

As part of the survey mentioned above, members of the TRB Freeway Operations Committee and Interchange Subcommittee were asked to identify the desirable features that should be provided, but are currently missing, from existing models. Their responses are summarized below.

1. Establish a methodology for the integrated capacity analysis of interchanges. The methodology should allow traffic engineers to compare different interchange forms. The analysis should yield a level of service index which reflects the geometry and traffic of the interchange area as a whole. Once the methodology is developed, an analytical software model, similar to HCS, will follow naturally.

2. For diamond interchanges, guidelines should be developed to relate the spacing between the two intersections to the traffic demand and turning patterns. Such guidelines will help traffic engineers to evaluate the performance of diamond interchanges, and in selecting between the CDI and SPUI forms. TRAF-NETSIM is one tool to help determine the relationship between traffic demand and the storage capacity between intersections.

3. Develop a comprehensive model for aiding the planning/design and interchange selection process. It is desirable to have a software model that can evaluate interchange geometric properties in addition to the traffic operations aspects of interchanges. Even though models like INTRAS or FRESIM allow users to enter superelevation and pavement friction, and the new NETSIM will generate safety-related MOE's, more features are needed in order to evaluate geometric properties satisfactorily. Ideally, the traffic engineer should be able to design the interchange and then use a performance model to evaluate the design in an interactive and user-friendly manner.

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DISCUSSION

Jim Powell, Session Moderator

This paper has presented a good overview of the software available for evaluating interchange operations and desirable extensions to this software. The authors have touched on most of the critical issues including: 1) the need to distinguish planning/design analysis from operational analysis; 2) operational complications such as arterial weaving and spillback; and 3) the alternate types of software tools—analytic, optimization and simulation.

One important aspect that should be discussed further has to do with use of microscopic simulation models such as NETSIM. Such models have powerful capabilities that capture many real world interactions. At the same time, a potential user needs to understand basic concepts of Monte Carlo simulation, the stochastic nature of modelled processes and the variability of the results.

A program such as NETSIM utilizes statistical distributions to model key aspects of traffic behavior, for example, driver type, and thus characterize such things as aggressiveness, car-following logic and lane changing behavior. Other distributions such as headway and deceleration profiles are used similarly by NETSIM. Inherently assumed is that the underlying distribution (e.g., mean, variance and shape) is well known for a given characteristic. That is, it has been verified in original model development, or has been input by the user based on observed field data. This is important when considering, for example, weaving behavior on arterials near interchanges, because weaving is dependent on complex interactions among a variety of vehicle and driver types under varying geometric and traffic control conditions.

As an example most of the NETSIM model was calibrated originally around 1973 using data primarily from Washington, D.C., and its ability to replicate real world conditions was very good for peak hour conditions, but not as good under less disciplined offpeak conditions (see *Network Flow Simulation for Urban Traffic Control System - Phase II*, Volume 1. Technical Report, by Peat, Marwick, Mitchell and Company, March, 1974; this still constitutes the base calibration for the model, per discussion with Henry Lieu). In practice few, if any, users have the ability to modify embedded distributions due to the amount and cost of required data collection. As a result, users effectively are modelling traffic using Washington, D.C. driver attributes. If the underlying distributions are not appropriate to the study area, the ability to simulate detailed vehicle interactions is questionable. In that case, model results are no more valid than those from macroscopic models that rely essentially on mean variable values instead of statistical distributions.

Related to the above, the processes and results of simulation models are stochastic in nature. This means that between different model runs, different answers can be achieved. Furthermore, as volume-to-capacity ratios at specific intersections or nodes approach 1.0—often the locations of greatest concern—the result variability from run to run increases to a maximum. For statistical validity then, it is necessary to conduct replications using different random number seeds. It is important that the user be aware of this fact, and be prepared to make multiple runs (see "Variability Assessment for TRAF-NETSIM", by Gang-Len Chang and Ammar Kanaan for recent discussion of this issue; ASCE *Journal of Transportation Engineering*, Volume 116, No. 5, Sept./Oct. 1990, pp. 636-657). Since runs of a microscopic model can require significant computer time, the user must budget time and money resources accordingly.

Another point is more practical. As noted in the paper, none of the microscopic models cited have signal timing (or other) optimization capabilities built in. As is apparent from use of any of the optimization models, interchange performance is very dependent on good signal timing. Thus to use effectively a microscopic model to evaluate alternate interchange forms, the user will typically need to run at least one of the optimization models to generate signal timings. For fair comparison between different interchange forms, the same optimization model should be used, yet some optimization models (e.g., PASSER III) are applicable to only one interchange form. The results from such an evaluation often are only as good as the timings produced by the optimized model(s), and even then the optimized timings may need to be "tweaked" to achieve reasonable results.

In broad perspective, microscopic models can be useful for investigating and understanding detailed traffic interactions—some users indicate that a simulation of existing conditions alerts them to conditions or phenomena they did not (or could not) observe in the field initially, but then do field verify. Testing of unusual traffic control or geometric features, as noted in the paper, can be first undertaken through simulation to avoid risky situations, or to eliminate the need to build an expensive facility. Because of the complexity of the models, however, there are theoretical and practical considerations of which the potential user must be aware. Not to take account of such considerations leaves the user in jeopardy of the basic rule of computing—"garbage in, garbage out."

A final point deals with potential use of the Highway Capacity Software (HCS) for weaving analysis on arterials. The entire topic of merge/diverge/weaving on freeways is under review currently as a part of NCHRP Project 3-37. Current procedures have been questioned in some respect and likely are to be updated in the near future; this suggests that the use of current freeway procedures to approximate arterial conditions should be undertaken with a good deal of caution.

REVIEW OF DIAMOND INTERCHANGE ANALYSIS TECHNIQUES: PAST AND PRESENT

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Introduction

The diamond interchange interface with arterial streets has long presented formidable challenges for the traffic engineer. Especially in urban areas, it usually results in two closely spaced signalized intersections, often in close proximity to other signalized intersections. Urban freeways often act as traffic generators themselves, which cause some of the highest volumes on arterial streets near the ramp or frontage road terminal. Additionally, the fact that there are typically few streets on which to cross from one side of a freeway to another further concentrates traffic on the arterial street. For these reasons, diamond interchanges often dictate the capacity of the entire arterial street.

These closely spaced, signalized intersections associated with diamond interchanges also offer some operational problems. The method of timing the signalized intersections has been the subject of considerable research and discussion. With the importance of these signalized diamond interchanges on the arterial streets, it is surprising that we have not developed better analytical techniques to predict their capacity. Of particular concern is the prevalent practice of treating the two signalized intersections independently