FINAL REPORT

EVALUATION OF METHODS FOR FREEWAY OPERATIONAL ANALYSIS

Catherine C. McGhee
Senior Research Scientist

Virginia Transportation Research Council
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ABSTRACT

The ability to estimate accurately the operational performance of roadway segments has become increasingly critical as we move from a period of new construction into one of operations; maintenance; and, in some cases, reconstruction. In addition to maintaining flow on our existing roadways, we are faced daily with issues of allocating funds to maintenance activities that will ensure the roadways continue to serve the needs into the future. This includes identifying needs for expansion; additional freeway interchanges; and changes in operational strategies, including HOV lanes or other lane restrictions designed to facilitate efficient traffic flow.

Limitations on available funding make up-front analysis of alternative improvement strategies even more important. Traditional methods of analysis such as those provided in the *Highway Capacity Manual* were not designed to address many of the issues that are commonly faced today. In response, traffic engineering professionals have begun to employ more advanced tools for operational analysis. These tools often involve simulation models that provide very detailed measures of performance based on detailed user input.

Based on the experiences of the Virginia Department of Transportation with respect to simulation models and the results of studies documented in the literature, basic guidelines are presented for the use of simulation analysis for freeways in Virginia. Several models we found to provide reasonable results in particular situations. It is, therefore, critical to identify the characteristics of the network to be analyzed and select the best tool based on these characteristics.

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INTRODUCTION

Departments of transportation across the nation are faced daily with the task of evaluating the operational characteristics of the roadways they maintain. Analyses are conducted to determine both existing and future conditions on arterials and freeways. With the increasing congestion that exists on many of these roadways, the need for accurate evaluations is critical.

Traditionally, these analyses have been conducted using procedures prescribed in the *Highway Capacity Manual* (HCM).[1] When congested conditions are present, however, the results of these procedures are less accurate in the measures of effectiveness they report. A study conducted by Arnold and McGhee of the Virginia Transportation Research Council found that use of the HCM procedures resulted in erroneous level of service (LOS) designations at signalized intersections where residual queuing was a problem.[2] This problem becomes more significant when the operational characteristics of corridors are evaluated. Traditional methods neither take into account the effect of adjacent intersections on each other nor account for the performance of an arterial intersection on nearby freeway ramps. In urban areas and many suburban areas, the interaction of arterial and freeway traffic has become significant. If a signalized intersection at the end of a freeway ramp is not functioning efficiently, traffic may quickly queue onto the freeway mainline, creating hazardous conditions. Likewise, if a freeway merge section is poorly designed, the vehicles entering the freeway will likely queue on the entry ramp and create queuing and congestion on the adjacent arterial.

The design of freeway weave sections, or sections where traffic streams must cross, is a key to the performance of the freeway as a whole. Poorly designed weave sections, for both merge and diverge operations, can lead to reduced capacity and safety. The HCM procedures for freeway analysis require separate analyses of ramps, weaving sections, and mainline sections.[1] By partitioning the roadway in this manner, the effects of one section on another are all but lost. Although the HCM does include a discussion of combining the results into an overall analysis, it also states "the extent of influence of any individual element can range from as little as several hundred feet to more than a mile. Inasmuch as it is not possible to exactly determine the extent of such impacts, weaving and ramp junction areas that operate at levels of service poorer than adjacent segments should be viewed with caution because they may affect the operation of upstream sections."[1] Methods of analysis that can overcome this limitation are now being sought by transportation professionals and the Transportation Research Board's (TRB) Highway Capacity Committee.

Arnold and McGhee[2] identified simulation analysis as a method of evaluating operational characteristics when traditional methods break down. Other methods that provide accurate estimates of performance under specific conditions were also identified. The current study was conducted to achieve a similar result with respect to freeway evaluation models.

PROBLEM STATEMENT

The Virginia Department of Transportation's (VDOT) policy on capacity analysis precludes the use of methods other than the HCM procedures. The limitations of these procedures have led to questions about the availability and accuracy of other methods. Limited information is available about the performance of other methods under varying traffic and geometric conditions. Before other models may be used by VDOT staff or those submitting work to VDOT, the strengths and limitations of the models must be investigated.

PURPOSE AND SCOPE

A revised policy could be established for VDOT through evaluating existing freeway operational analysis methods and establishing guidelines for their use. Such a policy would result in evaluations that are more accurate and, therefore, better designs. The purpose of this study was to evaluate the methods identified in the literature and attempt to identify guidelines for their appropriate use by VDOT. Models were evaluated based on typical VDOT applications and needs.

METHODS

There is extensive information in the literature regarding available methods for conducting analyses. Descriptions of the methods and limited evaluations and comparisons were identified, and pertinent information was obtained. In addition, many discussions were held with VDOT staff concerning current practices and the difficulties encountered with the practices. This information was assimilated to formulate recommendations for operational analyses within VDOT.

RESULTS

Review of Methods

VDOT has experience with several methods of evaluating freeway operations. The most common method, and the one used the longest, is that prescribed in the HCM.[1] This method is widely accepted and provides a LOS designation upon which many design criteria are based.

FRESIM, a freeway simulation model developed by the Federal Highway Administration (FHWA), was enhanced significantly in recent years, culminating in its inclusion in the model CORSIM, a combination of FRESIM and the arterial model NETSIM. The combination of the two models into one integrated model allows the user to do system-level analysis. INTEGRATION[3] is a privately developed and owned model currently maintained by Hesham Rakha and others at Virginia Tech.

Highway Capacity Manual

The procedures in the HCM are macroscopic in nature. They are based on relationships and equations developed over the years from data collected at various locations. The *macroscopic* designation means that the procedures consider groups of vehicles, rather than individual vehicles, and look at a specific time period, rather than a continuous time-step-by-time-step evaluation. Neither the interaction of vehicles nor the impact of varying driver and vehicle characteristics is measured.

According to the 1994 HCM, a freeway is "a divided highway facility with full control of access and two or more lanes for the exclusive use of traffic in each direction."[1] HCM further defines three types of component subsections: basic freeway sections, weaving areas, and ramp junctions. A basic freeway segment is any freeway segment that is not affected by merging or diverging movements at nearby ramps or weaving movements. When a merge area is followed by a diverge area (or an on ramp is followed by an off ramp), a weaving area is formed where the traffic streams must cross. Isolated or consecutive on ramps or off ramps are considered ramp junctions. Each segment type is associated with its own analysis procedure used to determine the operational characteristics of the segment (or LOS). The fact that HCM divides a freeway into these distinct segments is significant. Although the reasons for it are logical, flow conditions vary greatly across the three types of segments, and such disjointed analysis methods can lead to problems. In fact, HCM cautions users that the procedures of Chapters 3, 4, and 5 treat only the isolated characteristics of the segment under consideration. HCM states: "after analyzing the individual characteristics of a number of freeway segments, it is necessary to consider the total operation of segments as a unit."[1]

Basic Freeway Sections

Within basic freeway sections, density is used to define LOS. Density was selected as the parameter because it is sensitive to changes in flow throughout the range from zero to capacity. Table 1 lists the density ranges corresponding to the various LOSs of basic freeway segments. These densities result in average vehicle spacings that range from 161 m or 26 car lengths for LOS A to only 6 car lengths at LOS E. The increase in density reflects the restricted movement drivers experience. Speeds are also provided for the various density values and LOS levels. These speeds are expected values, and density remains the primary determinant in evaluating LOS.

Table 1. Level of Service for Basic Freeway Segments[2]

LOS	Maximum Density (pc/mi/lane)
A	10
B	16
C	24
D	32

For LOS E Free Flow Speed	Maximum Density (pc/mi/lane) 4-Lane Freeway	Maximum Density (pc/mi/lane) 6-Lane Freeway
70	36.7	39.7
65	39.3	43.4
60	41.5	46.0
55	44.0	47.9

pc = passenger car.

Weaving Sections

Three types of weaves are defined in Chapter 4 of HCM that are based on the characteristics of the weave section, primarily the number of lane changes required of the weaving vehicles.[1] For example, a Type A weave requires that each weaving vehicle make one lane change to execute the desired movements. In a Type B weave, one weaving movement may be accomplished without making any lane changes, and the other weaving movement requires at the most one lane change. A Type C weave is characterized by one weaving movement that may be accomplished without making a lane change, and the other weaving movement requires two or more lane changes. Limitations for the use of the weaving area equations are shown in Table 2. LOS within weaving sections is based on weaving and non-weaving speeds. Table 3 provides the LOS criteria for weaving sections.

Table 2. Weaving Area Limitations[1]

Type of Configuration	Weaving Capacity (pc/hr)	Maximum v/N (pc/hr/lane)	Maximum Volume Ratio (VR)		Maximum Weaving Ratio	Maximum Weaving Length
Type A	1,800	1,900	N 2 3 4 5	VR 1.00 0.45 0.33 0.22	0.50	2,000 ft
Type B	3,000	1,900	0.80		0.50	2,500 ft
Type C	3,000	1,900	0.50		0.40	2,500 ft

pc = passenger cars; v/N = volume per number of lanes.

Table 3. Weaving Area Level of Service[1]

Level of Service	Minimum Average Weaving Speed (mph)	Minimum Average Non-Weaving Speed (mph)
A	55	60
B	50	54
C	45	48
D	40	42
E	35/30	35/30
F	<35/30	<35/30

Ramp Junctions

The ramp junction methodology applies to the exclusive connection between two highway facilities. In cases where a ramp terminal involves a surface street junction, the procedures for signalized or unsignalized intersections must be used to assess the complete performance of the ramp. The ramp junction methodology estimates the performance of the ramp-freeway junction.

Studies have shown that most turbulence caused by merging and diverging at ramp junctions occurs on Lanes 1 and 2 within 457.2 m of the merge/diverge point.[1] Ramp junction LOS, therefore, is based on density within this influence area. Speed is provided as a secondary measure. The LOS criteria for ramp-freeway junctions are shown in Table 4.

Table 4. Ramp Junction Level of Service[2]

Level of Service	Maximum Density (pc/mi/lane)	Minimum Speed (mph)
A	10	58
B	20	56
C	28	52
D	35	46
E	>35	42
F	-	-

pc = passenger car.

Simulation Models

INTEGRATION

INTEGRATION was originally developed as what some termed a mesoscopic model. The term *mesoscopic* was used because although traffic flow was represented as a series of individual vehicles, as in microscopic models, each vehicle followed prespecified macroscopic traffic flow relationships rather than relying on car following and lane changing logic to control the movement of vehicles.[3] The model was modified to include both car following and lane changing logic and is now commonly accepted as a microscopic model. INTEGRATION tracks the lateral and longitudinal movements of individual vehicles at a resolution of up to one deci-second. The model does still employ the macroscopic traffic flow principles with respect to the speed-flow-density relationships that control link capacity.

Other improvements to the model include features for modeling toll plazas, vehicle emissions, weaving sections, and HOV lanes. The ability to model incidents is also provided, with incident severity described as the percentage of capacity lost to the incident. One of the most powerful features of INTEGRATION is the dynamic traffic assignment routines that incorporate real-time link travel times and, therefore, can model the effectiveness of many intelligent transportation system (ITS) technologies such as traveler information systems and in-vehicle route guidance systems. INTEGRATION can also model the presence of loop detectors and vehicle probes.[3]

The model accommodates both freeway and arterial roadways and differentiates between them only with respect to the capacity, speed, and jam density values entered for each link. Because of the model's reliance on macroscopic traffic flow relationships, nominal capacity (without regard for signals or incidents), free speed, speed at capacity, and jam density must be provided for each link.

CORSIM

CORSIM is part of the TRAF family of models developed by FHWA. CORSIM, short for corridor simulation, is a combination of the arterial model NETSIM and the freeway model FRESIM. The combination of the models allows users to conduct system-level analyses of networks including both freeways and arterials. CORSIM can be used for networks containing only freeway links or only arterial links, or combinations of the two; however, in reality, performance of one portion of the network often affects the other and necessitates a combined analysis. CORSIM is a microscopic simulation model that tracks the position and movement of each vehicle in the network once each second. The movement of vehicles is based on car following theory and random effects caused by differences in driver behavior and vehicle performance.

With respect to freeways, CORSIM is capable of modeling up to five mainline lanes, up to three auxiliary lanes, and one to three lane ramps. The model can also measure the impacts of restricted use lanes, HOV, incidents, and ramp metering and can replicate the presence of surveillance detectors.[4]

The most recently released version of CORSIM is Version 4.32, which has several enhancements. These enhancements include changes to the lane changing and car following behavior under congested conditions on short links, increases in the maximum number of vehicles that can be processed in any given time step, and removal of the limitation of the maximum number of vehicles that can be processed during the length of the simulation. In addition, the maximum numbers of links and nodes are increased to 1,000 and 500, respectively, in both NETSIM and FRESIM. A common complaint with FRESIM logic was the user's inability to control the percentage of specific vehicle types exiting at any given off ramp. The percentage of mainline vehicles exiting at any ramp was equally applied to all vehicle types so that if 20 percent of vehicles were coded to exit, 20 percent of the automobiles and 20 percent of trucks would exit. A record type now allows users to specify multipliers for specific vehicle types so that they will have different turning fractions for specific ramps.[5]

One of the most commonly requested enhancements to FRESIM was HOV logic. What is termed a "preview" version of this logic is included in version 4.32; complete incorporation is due in version 5.0. The new logic allows the user to specify up to three high-occupancy vehicle (HOV) lanes on any mainline or ramp link. HOV lanes can be exclusive or not, restricted to carpools only, restricted to buses only, restricted to carpools and buses, open to all traffic, or closed to all traffic. In addition, the logic is integrated with the ramp metering logic to allow HOV lane bypass at meters. With respect to ramp meters, Version 4.32 allows new metering algorithms. Car following sensitivity factors are now input in hundredths of a second and can be specified by link.[5]

CORSIM is public domain software and is available for purchase through McTRANS at the University of Florida where staff also provide technical assistance to registered users.

Literature Review and Comparison of Methods

A number of studies have attempted to tackle the task of comparing various analysis methods. Differences in the models and the data each requires often made these tasks more difficult. The experiences gained in the process of the comparisons are worthy of discussion here and provide significant insights into the strengths and weaknesses of the various models.

Prevedouros and Wang Study

Prevedouros and Wang compared the results of three models, INTEGRATION, CORSIM, and WATSim, as they were applied to a large (20-km) freeway/arterial network.[6] Prior to the large network trial, the models were applied to a smaller scale application. All three models were applied to three heavily loaded traffic networks for which exact volumes and speeds were known from field data. All three models produced reasonable and comparable simulated results on most of the tested network links. A limitation identified by the study was the large number of parameters that required modification to calibrate the models effectively to replicate observed field conditions. None of the three models satisfactorily replicated field conditions using default parameter values. The smaller scale study summarized the strengths and weaknesses of the models.

The findings with respect to CORSIM and INTEGRATION were as follows:[6]

- *CORSIM* has the most realistic lane-changing maneuvers. However, car following parameters corresponding to capacities as high as 3,000 vphpl were required to duplicate field conditions. Specification of off-ramp percentages rather than volumes was a problem as a number of vehicles were reported to miss their off-ramp destination when the necessary lane changes to access the off ramp could not be executed. This behavior is not typically observed in the field. Although some drivers do miss their intended exits, the number of vehicles observed to do this within particular CORSIM model runs is unrealistic. Compounding this problem is the fact that the model reassigns these vehicles to continue on a straight path through the network. Since future off-ramp volumes are calculated as a percentage of the total mainline volume, a substantial increase in mainline volume caused by a high number of reassigned vehicles will alter the off-ramp volumes downstream of the missed exit.

- *INTEGRATION* is the only model that can simulate the U-turn movement but has the most limited ability to simulate signalized intersections. Optional lane striping adds flexibility but lane changing did not match local behavior and was not configurable.

Table 5. Base Parameters Used from Prevedouros/Wang Study[6]

Parameter	Freeway	Ramp	Vineyard Blvd.	Other Streets
Saturated flow rate (vphpl)	2300	2000	1900	1900
Free-flow speed (km/hr)	105	65	55	50
Speed at capacity (km/hr)	55	32	32	25
Jam density (v/km/l)	150	150	150	150

The application of the models to the larger, integrated network was intended to test the applicability of the earlier results. Model runs were limited to 15 minutes in this study.

Although all signalized intersections in the network operate as actuated, timing parameters were averaged and approximated as pretimed in the models. This was done in part because INTEGRATION can model only pretimed signals. For consistency, a set of base parameters was developed for the initial runs with each model. Parameters were altered as needed during the calibration phase. The base parameters are shown in Table 5. The results of the larger model runs revealed several issues relating to the two models:

- *INTEGRATION* simulation revealed several model problems involving lane changing in weaving sections and left-turn maneuvers. Specifically, within one weaving section, exiting vehicles remained in the left lanes until the diverge point of their intended off ramp, at which point they waited for gaps in traffic to make the lane changes necessary to exit. This unrealistic behavior resulted in excessive delays throughout the network. Changes in the lane-striping file overcame most of this behavior. Limitations on signal phasing presented a problem for permitted/protected left-turn movements that are served by three signal phases (exclusive left, left-through, exclusive through) because any link may be served by only two phases. Lane alignment also caused problems on some links.

- *CORSIM* modeling required changing the freeway car following parameters from the default values, effectively increasing capacity from 2,350 to 3,300 vphpl. Lane changing parameters also required modification. The arterial portions of the network responded adequately to the default parameters.

Study conclusions indicated that CORSIM and INTEGRATION produce acceptable results. CORSIM was slightly better than INTEGRATION. INTEGRATION had advantages in planning applications where routing was an issue (although this was not specifically tested as part of the study, the capability was acknowledged).[6]

Roess and Ulerio Study

In NCHRP Study 385, Roess and Ulerio compared the results of the HCM ramp analysis procedures and the FRESIM model.[7] The objectives of the research were to identify and investigate the following:

- common ranges of application and where one or the other model might be inappropriate

- consistency of the internal logic in each model

- consistency of results when both models are applied to the same case

- comparative sensitivities of the models to key input variables

- potential modifications to models that would improve the consistency of results when both models are properly applied.

NCHRP Study 85 was based on a 1994 release of FRESIM, before its incorporation into the CORSIM model. The study was limited by the fact that FRESIM was a "work in progress." The beta test version of CORSIM was released during the preparation of the final report. Several of the limitations identified by the study were overcome in more recent model releases. One FRESIM deficiency noted was the tendency of drivers to merge within 30.5 m of the gore area of an on ramp. Field data indicated that drivers will take advantage of more of the acceleration lane before merging. This deficiency appears to be overcome in the latest release of CORSIM. The merging behavior of the on-ramp vehicles appears to be sensitive to on-ramp free-flow speed. Another limitation of the model identified in the study involved the number of vehicles that failed to exit at their intended destination. FRESIM (and the current version of CORSIM) allows a vehicle to miss an assigned destination (off ramp) if the driver is unable to execute the lane changes necessary to access the ramp. This behavior does not occur in the field and leads to inaccurate off-ramp volumes in the model. A third limitation of the earlier model was the inability to specify the percentage of heavy vehicles that will exit at any given off ramp. This limitation was corrected in CORSIM Version 4.32.[5]

The overall findings of NCHRP 385 indicated that the results of FRESIM are too inconsistent with the 1994 HCM results for it to be acceptable for use as an alternative for location-specific analyses. The authors do qualify this finding with the statement that FRESIM has a great deal of promise and could prove to be a valuable tool once the identified limitations are addressed.[7]

Skabardonis Study

In May 1999, Skabardonis reported on his evaluation of several simulation models for their ability to meet the needs of the Washington State Department of Transportation (WSDOT).[8] The objective of the study was to develop recommendations and guidance on the selection and practical application of simulation models. With respect to each model, the study addressed the following questions: (1) when to use which model for the various WSDOT analysis needs; (2) what are the specific model strengths and weaknesses; (3) what type/amount of modeling effort, costs, and expertise are required; and (4) what are the requirements for training and technical support. Each model was evaluated on the following parameters:[8]

- *Model capabilities/features.* Can the model handle the WSDOT modeling needs and priorities for corridor planning/operations, freeway operations, and arterial operations?

- *Modeling of traffic flow.* Can the model accurately simulate the variability in traffic demand in time and space and model the growth/interaction and decay of traffic queues and the capacity reductions caused by incidents and bottlenecks?

- *Input data requirements.* How much field data are required and to what level of detail for the model application? What are the data requirements for the model calibration/validation? What level of effort is involved in coding input data?

- *Output options.* What performance measures are provided by the model? Are linkages provided between model results and HCM measures for LOS analysis? What types of graphic displays and animation features are provided?

- *Computational aspects.* Are there specific computer platform requirements for the software? What are the typical software run times? Are there any special software and hardware requirements to support the model?

- *Costs.* What are the average staff time and expertise required for the model application? What are the costs for software acquisition and maintenance? What formal training is needed to apply the model? What are the typical costs for training and technical assistance?

Early in the project, a workshop was held with WSDOT staff to determine their needs with respect to the various modeling tools. They identified several concerns with respect to using simulation models, including uncertainty about the relationship between simulation models and other techniques, particularly the HCM LOS; questions regarding the consistency of results; and the question of which model to use given the data available (and what that might mean in terms of model accuracy).

Skabardonis built on the work of a previous study conducted at the University of California at Berkeley that found CORSIM and INTEGRATION to have the highest probability of successful implementation in real-world applications of the models evaluated.[6] In addition to those two promising models, three models were selected for evaluation based on WSDOT's needs. The five models included in the study, therefore, were CORSIM, INTEGRATION, MITSIM, PARAMICS, and VISSIM. MITSIM is a microscopic simulator developed at the Massachusetts Institute of Technology and used only internally for evaluating traffic management options and ITS applications. PARAMICS is a model developed in the United Kingdom, and VISSIM is a microscopic model developed in Germany.

The study compared the input requirements and output for the various models. A common complaint against the use of simulation models is that they require a great deal of data. Skabardonis pointed out that the field data for the models' application were similar to the field data required to perform analyses in accordance with HCM or other traffic operations tools.[8] The majority of supply data is common to most of the selected models. This would include roadway geometry and lane usage. Traffic demands for the CORSIM and VISSIM models are specified in terms of entry volumes and turning fractions at network nodes. Both models will also accept origin-destination (O-D) data. Traffic demands for INTEGRATION, MITSIM, and

PARAMICS are specified only in terms of time-dependent O-D flows. With respect to control logic, CORSIM models NEMA and 170 dual-ring actuated signal controllers. INTEGRATION models only fixed-time control.

CORSIM was identified by the study to have the most comprehensive measures of effectiveness (MOEs) of traffic performance (travel time, speed, delay, stops, queue lengths) for each movement, link, and section of network and the total network.[8] CORSIM also provides fuel consumption and emission data by link and for the total network by vehicle type. INTEGRATION output includes travel time, delay and number of stops for each link, vehicle type, O-D pair, and network-wide values of fuel consumption and emissions. Unformatted output files may be processed through spreadsheets and other software to create customized reports.

Skabardonis included the HCM/LOS performance measures compared to output provided by the simulation models described in Table 6. The models do not necessarily make the LOS calculation directly but do provide the parameters required.

The Skabardonis study indicated that there is no "ideal" model currently available that can explicitly address all of WSDOT's needs. CORSIM was ranked as the best model for addressing freeway operations, and INTEGRATION ranked second. The study found that the explicit modelings of freeway, arterial, and intersection designs, including multiple vehicle types and various control options, were strengths of the CORSIM model. Limitations of the model included the inability to model HOV lanes, the lack of a traffic assignment module, and limitations on the size of the network that could be modeled. Some of these limitations were overcome (the latest version of CORSIM includes HOV lane modeling logic and increases in the maximum number of links and nodes[5]), and the issue of traffic assignment is being addressed through an interface to FHWA's dynamic traffic assignment (DTA) algorithms currently in testing. CORSIM is also widely used by both practitioners and researchers. INTEGRATION also includes explicit modeling of integrated freeway and arterial networks and has the added benefit of incorporating several options for traffic assignment. The study found INTEGRATION to be the most comprehensive single model for corridor planning and ITS applications. Limitations of the model included the use of macroscopic speed-flow-density relationships in car following algorithms and the approximations used in the analysis of some design and control features.

Table 6. Performance Measures Included in CORSIM and INTEGRATION[8]

Facility Type	Performance Measure	CORSIM	INTEGRATION
Freeway sections	Density	X	X
Weaving	Average speed (mph)	X	X
Ramps	Density	X	X
Freeway systems	Average speed (mph)	X	
Interchange ramp terminals	Travel time (s/vehicle)	X	X

VDOT Needs and Experience

VDOT has traditionally used the methods in HCM[1] when analyzing freeway operations and facility design. In more recent years, VDOT has recognized that there are limitations to these procedures and have looked to simulation to provide more accurate analysis results. This is a change in both practice and mindset for engineers in VDOT. Similar to practitioners across the country, VDOT engineers have extensive experience applying the HCM methods and much more limited experience with simulation models. They are comfortable with the LOS designations used to communicate the performance of an existing freeway or a proposed design. Making the change to the more complex simulation analysis must be justified in terms of improved results that lead to better field implementations.

Specifically, VDOT conducts freeway operational analyses for a number of reasons:

- to determine the impact of alternative design strategies (including design of weaving sections)
- to measure the impacts of work zones or incidents
- to plan for exclusive or restricted facilities or lanes (i.e., truck lanes and HOV facilities)
- to determine the need for additional infrastructure (required number of lanes or CD (collector distributor)/frontage roads, new interchanges
- to estimate the impact of implementing various ITS strategies.

In some cases, these needs are met by traditional HCM methods, but many times, they are not. In fact, several recent projects illustrate the need for simulation in VDOT's analysis toolbox. They also illustrate the need for expertise and guidelines on the use of simulation models. Brief descriptions of two projects are included to illustrate VDOT's needs with respect to simulation modeling. The projects illustrate VDOT's recognition of simulation modeling as a valuable tool along with some of the difficulties that need to be addressed to use these models effectively.

Illustrative Projects

Freeway Improvement Study

VDOT was considering the long-term needs in a corridor that includes an interstate highway serving both local and long distance travel. A group of consultants was hired to conduct the required analysis. The highway serves a large percentage of trucks in the traffic stream that adds a level of complexity to the operations. There was a need to evaluate the performance of the highway with and without truck restrictions that would prohibit trucks from using the left-most lane. Because of the limitations of the HCM procedures discussed earlier, simulation modeling was chosen as the analysis tool. Many issues regarding the application of the model came up throughout the life of the project. Because of the "newness" of the method, the project was more difficult to manage and presented challenges that were new to responsible VDOT staff.

A big issue for VDOT in this project was the calibration of the base model. A number of questions arose concerning the fact that the time frame under study was a 20-year planning horizon. The issue was the appropriateness of calibrating to existing conditions given the unknown changes that may occur with respect to driver and vehicle characteristics in the span of 20 years. The fact that the analysis was being conducted by a number of consultants working independently only reinforced the need for a set of agreed upon guidelines.

Development Impact Study

The lack of written guidelines for model implementation were also a factor in a study to evaluate the impact of a large development planned adjacent to an existing highway. The analysis included evaluating the impact of adding an interchange between two existing interchanges on the freeway as well as the operations of adjacent arterial roadways with the additional traffic loading. The high volume of traffic on the freeway and the arterial roadways made this a complex situation. The need to analyze the total system performance (both freeway and arterial) led to VDOT's decision to use simulation modeling as opposed to HCM procedures. Calibration of the model was again an issue as was VDOT's need to have a LOS designation as the result of the analysis.

Staff Concerns

The concerns of VDOT staff charged with the responsibility of determining the operational characteristics of Virginia highways currently and with planned improvements are similar to those of the WSDOT staff previously discussed.[8] By far, the biggest concern is how to deal with the issue of LOS determinations. Even when alternate methods (as opposed to the HCM) are used or accepted from others by VDOT, a LOS designation is required as the final determination of operational acceptability. An equally important concern is determining when a method is appropriate for use and when it is not. Differences in the capabilities of the models often make one more appropriate than another. A third issue of concern for VDOT staff is calibration. It is understood that without proper calibration, the results of model use are highly suspect but the process of calibration remains somewhat of a mystery.

DISCUSSION AND CONCLUSIONS

In recent years, VDOT has undertaken a number of complex freeway operational analyses for various reasons relating to planned improvements, widenings, or new construction. VDOT has primarily relied on FRESIM/CORSIM for these analyses when simulation was deemed appropriate. A number of the limitations of such analyses discussed in this report have caused difficulties for VDOT and consultants hired by VDOT. The single biggest difficulty has been the network size limitation imposed by the current version of CORSIM. The Skabardonis report[8] estimated the maximum practical network size at 16.1 km. In analyzing future condition scenarios, VDOT has encountered difficulties achieving desired throughputs in much smaller networks. It is recognized that these difficulties in some cases may be attributable to a lack of adequate calibration of the model. VDOT is now expanding its analysis toolbox to include the INTEGRATION model with assistance from the model developers at Virginia Tech. The ability of INTEGRATION to process large networks will allow VDOT to overcome some of the limitations imposed by CORSIM.

Based on the literature and VDOT's experience, it is clear that VDOT's policy restricting operational analyses to the use of the HCM procedures is no longer prudent. Complex roadway geometry and higher traffic volumes are rendering the results of these traditional methods inaccurate. VDOT planners recognize this and have begun to employ simulation models in conducting operational analyses. The HCM methods still have a prominent role in all operational analyses, however, as evidenced by the fact that there remains a desire to report a LOS at the end of the analysis, regardless of how it is performed. Current practice in VDOT is to manipulate the results of all operational analyses to convert available MOEs to LOS designations. For example, the density values provided by a CORSIM analysis are used to establish a basic freeway LOS designation.

Simulation models have been successfully deployed in countless projects nationwide, and the results of the analyses have been validated based on observed and measured field conditions. There are differences in the available models that preclude the selection of one model as the ideal choice in all cases. Instead, it is important that the transportation professional look at the situation to be analyzed, the geometric and operational characteristics to be modeled, and the level of detail required in the output and select the most appropriate tool.

Adequate, accurate model calibration is a critical, yet often overlooked, aspect of all simulation analyses. Proper calibration ensures that the various driver and vehicle characteristics assumed by the model logic are applicable to the area under study. It may be the case that drivers in New York City have different gap acceptance, lane changing, and headway characteristics than drivers in a more rural area. In addition, some roadways might have a very different vehicle mix (percentages of various vehicle types, e.g., high-performance autos, low-performance autos, trucks, buses). The characteristics can have a significant impact on the results of the analysis. For example, vehicles with drivers who typically follow at an average of 2-second headways will lead to a capacity value of approximately 1,800 vehicles per hour per lane. Decreasing that average headway to 1.8 seconds will effectively increase the capacity to 2,000 vehicles per hour per lane.

The parameters used for model calibration will vary from one model to another. The first step in calibration is to compare the results of the base model (existing conditions) and the data collected in the field. It is important to note any discrepancies between the simulated and field data with respect to speed, throughput, or, in some cases, queue length. Once a discrepancy is identified, the potential causes must be isolated. For example, is there a ramp nearby that might be contributing to the discrepancy? Are drivers following others more closely than the default value and distribution? Based on the answers to these questions, parameters should be altered in an iterative fashion until the best fit for that parameter is found. In some cases, multiple parameters will need to be altered to achieve calibration of the network.

The results of many comparisons and evaluations conducted of CORSIM and INTEGRATION, the two most widely used models, indicate that both can produce accurate performance measures when applied under appropriate conditions with care given to the calibration process.

RECOMMENDATIONS

1. *Establish a core group of experts with respect to operational analysis methods within VDOT.* Regardless of whether VDOT is conducting an operational analysis with in-house staff or contracting that work to a consultant, the responsibility to ensure that the results are reasonable rests with VDOT. A core staff within VDOT, knowledgeable in the capabilities and limitations of the available models, is, therefore, essential.

2. *Whenever an operational analysis is required (whether the analysis is conducted by VDOT staff or consultants), VDOT staff should consider the following*:

   - *Consider all aspects of a project before selecting a method.* The first step is to assess the situation to be analyzed and the level of detail required from the results. If a basic design analysis is needed to determine the number of lanes required on a basic freeway section (without weaving or ramp interference), the methods in the latest edition of the HCM (computerized in the Highway Capacity Software) should be sufficient. If restricted lanes (e.g., truck-restricted lanes and HOV lanes) are to be considered, a simulation model should be used to determine the impact of the restrictions. When high volumes are present, weaving is taking place, or ramp junctions are believed to result in excessive turbulence in the flow, simulation models will provide a more accurate representation of conditions. If simulation is determined to be necessary, the strengths and weaknesses of the models compared to the situation to be analyzed should be considered. If there is a need to model a 160.1-km corridor continuously, CORSIM is not likely the best method. INTEGRATION was designed to model these situations. If accurate modeling of complex weaving areas is sought, CORSIM should be applied to such areas. The microscopic car following and driver behavior modeling will provide a detailed analysis of the weaving maneuver. If the impact of route diversion or ITS strategies is to be measured, INTEGRATION is, again, the best tool since it incorporates a dynamic route assignment capability.

   - *Consider data availability and quality. For successful application, accurate information regarding geometry and operational details must be available. Because of the detailed nature of simulation models, any inaccuracies in input will be magnified in the output derived by the model. Availability of input data should be a primary consideration in selecting an analysis method.*

- *Pay particular attention to model calibration.* Once a simulation model is chosen, it must be carefully calibrated using data collected on existing conditions. Even if the purpose of a study is to consider a future condition, the existing geometry and operational characteristics should be coded in the model and the model-generated output compared to conditions observed in the field. Throughput and speed are two easily verified parameters. It is important to consider both ramp and mainline conditions as well as conditions by lane rather than average across all lanes. Examples have shown that acceptable average speeds can exist on a link as a whole while unacceptable conditions exist within the weaving traffic on the link.

3. *Look beyond LOS designations.* For a better understanding of the situation under study, all available measures of effectiveness should be considered. When required, model output may be manipulated to derive LOS designations. It is important to realize that these designations take very detailed measures of effectiveness and simplify them. VDOT should become an advocate for change in the FHWA design requirements that require a minimum LOS.

FUTURE CONSIDERATIONS

An important consideration for the continued use of any operational analysis methodology is a commitment to ongoing model maintenance and enhancement. As a product of the TRB, the highway capacity methodology is continuously reviewed and modified as necessary. In recent years, FRESIM, the freeway logic within CORSIM, has also been modified, first to incorporate it within CORSIM to allow for a systems level analysis and to enhance the car following logic and weaving behavior. INTEGRATION has expanded from a "mesoscopic" model to a microscopic model. There is uncertainty with regard to the future direction of the CORSIM and INTEGRATION models.

Much discussion has taken place in recent years regarding the future of CORSIM. The underlying code on which the model is built is 30 years old and has undergone many "fixes" over the years. The programming language is FORTRAN, which is considered inefficient by today's standards. FHWA recently issued a public request for information with regard to the future of the CORSIM model and what the next steps should be. Options include "re-engineering" the model to bring it up to today's software engineering standards and replacing the model with a new model. FHWA is also seeking input as to the best way to move forward, whether model development should continue to be a federally sponsored effort or the private sector should take the lead. VDOT should continue to monitor the status of these developments and provide comments when appropriate.

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