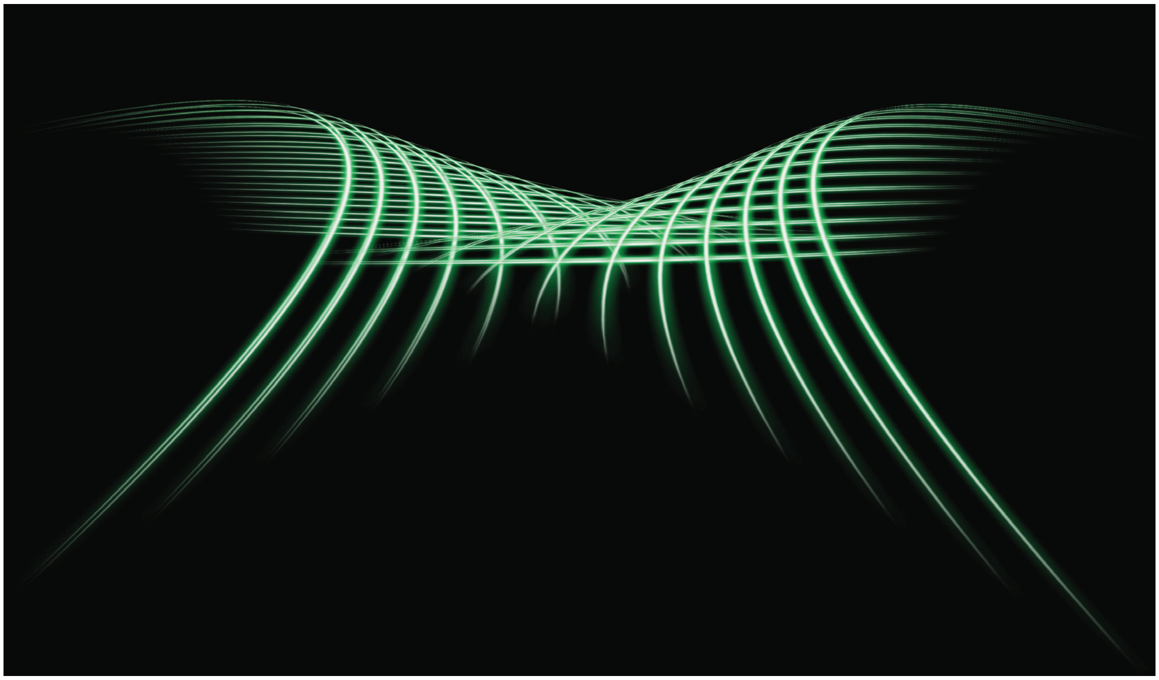
HCM2010

HIGHWAY CAPACITY MANUAL



CHAPTER 6

HCM AND ALTERNATIVE ANALYSIS TOOLS

TRANSPORTATION RESEARCH BOARD
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HCM2010

HIGHWAY CAPACITY MANUAL

The HCM 2010 significantly enhances how engineers and planners assess the traffic and environmental effects of highway projects by

- Providing an integrated multimodal approach to the analysis and evaluation of urban streets from the points of view of automobile drivers, transit passengers, bicyclists, and pedestrians;
- Addressing the proper application of microsimulation analysis and the evaluation of the results;
- Examining active traffic management in relation to demand and capacity; and
- Exploring specific tools and generalized service volume tables to assist planners in quickly sizing future facilities.

The HCM 2010 consists of four volumes:

Volume 1: Concepts;
Volume 2: Uninterrupted Flow;
Volume 3: Interrupted Flow; and
Volume 4: Applications Guide (electronic only).

The four-volume format provides information at several levels of detail, to help users more easily apply and understand the concepts, methodologies, and potential applications.

Volumes 1, 2, and 3 are issued as a boxed set. Volume 4 is electronic only, accessible to registered HCM users via the Internet, and includes four types of content: supplemental chapters on methodological details and emerging issues; interpretations, clarifications, and corrections; comprehensive case studies; and a technical reference library.

To order HCM 2010, go to **http://books.trbbookstore.org/hcm10.aspx.**

For more information about HCM 2010 and TRB publications, contact the Transportation Research Board Business Office, 500 Fifth Street, NW, Washington, DC 20001 (telephone 202-334-3213; fax 202-334-2519; e-mail TRBsales@nas.edu; or through the Internet, www.trb.org).

CHAPTER 6
HCM AND ALTERNATIVE ANALYSIS TOOLS

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1. INTRODUCTION

VOLUME 1: CONCEPTS
1. HCM User's Guide
2. Applications
3. Modal Characteristics
4. Traffic Flow and Capacity Concepts
5. Quality and Level-of-Service Concepts
6. HCM and Alternative Analysis Tools
7. Interpreting HCM and Alternative Tool Results
8. HCM Primer
9. Glossary and Symbols

It is well recognized that the models of the *Highway Capacity Manual* (HCM) are part of a continuum available to the analyst for highway capacity and quality-of-service analyses. For example, transportation planners and engineers have different needs in scope and level of detail. Planners focus on network performance in broad, general terms to understand supply–demand interactions between network capacity and flows. Of primary interest are the interactions of land uses and the transportation system. Engineers, in contrast, need to know how changes in the design of a specific system element or changes in the way it operates will affect its performance in terms of capacity, delays, queuing characteristics, and other measures. As a result, different traffic analysis tools are available to serve different analysis needs.

Chapter 6, HCM and Alternative Analysis Tools, begins by describing the HCM-based tools available to the analyst. In an *operations-level analysis*, which is one such tool, HCM methodologies are applied directly and the user supplies all required inputs to the procedure. Many planning, preliminary engineering, and design applications do not require the level of accuracy provided by an operations analysis and substitute *default values* for some (or nearly all) of a methodology's inputs. *Generalized service volume tables* are sketch-planning tools that provide an estimate of the maximum volume a system element can carry at a given level of service (LOS), given a default set of assumptions about the system element. The use of local default values and local generalized service volume tables helps reduce the uncertainty in the results of analyses that use these tools, compared with using the HCM's national default values and tables. The chapter's two appendices provide guidance on developing local default values (Appendix A) and generating local generalized service volume tables (Appendix B).

Analysts might consider alternative tools as a supplement to HCM methods for a variety of reasons. Alternative tools might be considered in the following analyses, among others: those outside the range covered by an HCM methodology, those requiring performance measures not produced by the HCM, and those where the quantity of data required makes HCM methods impractical. To assist analysts in evaluating and applying alternative tools, this chapter describes traffic modeling concepts and terminology, identifies conceptual differences between analytical and simulation tools, provides a framework for applying alternative tools, and lists criteria to consider in the selection of a traffic analysis tool.

2. HCM-BASED TOOLS

GENERALIZED SERVICE VOLUME TABLES

Service volume tables provide estimates of the maximum number of vehicles a system element can carry at a particular LOS, given a set of assumed conditions.

A service volume table provides an analyst with an estimate of the maximum number of vehicles that a system element can carry at a given LOS. The use of a service volume table is most appropriate in certain planning applications in which evaluation of every segment or node within a study area is not feasible. Examples of these applications are city, county, or statewide planning studies where the size of the study area makes a capacity or LOS analysis for every system element infeasible. For these types of planning applications, the focus of the effort is to highlight potential problem areas (for example, locations where demand may exceed capacity or where a desired LOS threshold may be exceeded). For such applications, a service volume table can be a useful sketch-planning tool, provided the analyst understands the limitations of this method. Once potential problem areas have been identified, other tools (HCM-based or alternative) can be used to perform more detailed analyses for locations of interest.

As described in more detail in Appendix B, generalized service volume tables are developed by holding constant all input values to a particular HCM methodology—except demand volume. Demand volume is increased until the measure of effectiveness (MOE) for the methodology reaches the threshold for a given LOS (e.g., the threshold between LOS B and C). That demand volume then becomes the *service volume* for the given LOS (in the example above, for LOS B). The service volume represents the maximum number of vehicles that the system element can carry at the given LOS, given the assumed inputs.

Service volume results should be applied with care, since actual conditions will likely vary in some way from the assumptions used to develop the table.

The characteristics of any given system element will likely vary in some way from the assumed input values used to develop a service volume table. Therefore, the results from a service volume table should be treated as rough approximations. Service volume tables should not be used as a substitute for other tools when a final determination of the operational adequacy of a particular roadway is made.

The assumptions built into a table may be average (or typical) values or conservative values. The choice affects how results from the table are interpreted.

Service volumes can be sensitive to the choice of input values, depending on the particular methodology and input parameter.

For ease of use, generalized service volume tables require a minimum of user inputs—typically, key design parameters that have the greatest influence on a facility's capacity and LOS, such as the number of lanes. Given these inputs, a user can then read the service volume for a given LOS directly from the table and compare it with the actual or forecast volume for a system element. A volume greater than the service volume for the desired LOS indicates the need for further analysis. Depending on the assumptions used to develop the table (i.e., average or typical values versus conservative values) and the sensitivity of the service volumes to the default values used, volumes somewhat less than the identified service volume (as much as 25% below the service volume in some cases) could also suggest the need for further analysis.

APPLICATION OF DEFAULT VALUES TO HCM METHODOLOGIES

Many planning, preliminary engineering, and design analyses apply HCM methodologies directly but use default values for some or many of the input parameters.

In most planning, preliminary engineering, and design applications of the HCM, an analyst applies an HCM methodology taken directly from one or more of the chapters in Volumes 2 and 3 but uses default values for some (or many) of the input parameters. These types of analyses are frequently used to evaluate or design for future operations. Therefore, not all of the input parameters required by an HCM methodology (e.g., heavy-vehicle percentage or peak hour factor) may be available or readily forecast. Default values can also be applied when current operations are evaluated as part of a screening effort, similar to the way service volume tables are applied. Because users have control over which input parameters are defaulted, the uncertainty of the analysis results is reduced compared with the application of a service volume table, which potentially reduces the number of problem areas flagged for further analysis.

Although the HCM provides default values for a number of methodologies, the analyst should be mindful that these values represent typical national values and that typical conditions within a state, region, or community may be different. When default values occur frequently in analyses, the use of local default values can help further reduce the uncertainty in the analysis results. Appendix A provides guidance on developing local default values.

OPERATIONS-LEVEL HCM ANALYSIS

Operations-level HCM analyses apply the HCM methodology directly and use no, or minimal, default values.

In an operations-level analysis, an analyst applies an HCM methodology directly from one or more of the chapters in Volumes 2 and 3 and supplies all of the required input parameters from measured or forecast values. No, or minimal, default values are used. Therefore, compared with generalized service volume tables and the application of default values, operations-level analyses provide the highest level of accuracy. However, as discussed in Chapter 7, Interpreting HCM and Alternative Tool Results, analysts must still account for variability, uncertainty, and measurement errors in input data, and their impact on the analysis outputs, in the interpretation of analysis results.

The chapters in Volumes 2 and 3 identify methodological limitations and special cases where analysts may wish to consider alternative tools.

An operations-level analysis is applicable to any situation covered by an HCM methodology. Analysts should refer to the Limitations of the Methodology and Special Cases sections of the HCM chapter that covers the system element being evaluated to ensure that the HCM methodology is appropriate for the specifics of the situation being studied. A situation that is outside the range of conditions covered by the methodology would be one reason for considering an alternative tool. Other cases when alternative tools might be considered are discussed in the next section.

3. ALTERNATIVE TOOLS

OVERVIEW

Alternative tools include all non-HCM procedures that may be used to evaluate highway system performance.

Alternative tools include all analysis procedures outside of the HCM that may be used to compute measures of transportation system performance for analysis and decision support. Most alternative tools take the form of software products, and there is an abundance of literature describing alternative tools and their applications. The purpose of this section is to categorize the most commonly used tools, to identify the conditions under which they might be used to supplement the HCM procedures, and to suggest a framework and guidelines for their application that will maximize their compatibility with the HCM deterministic procedures. The intent is not to identify or compare specific tools or to duplicate the wealth of literature that exists on the general subject of traffic performance analysis.

This section describes the types of available tools (which are generally software products) but does not identify or compare specific tools.

Clearly, readers should use the material presented here in conjunction with other documents that also address analysis, modeling, and simulation of transportation systems. A considerable volume of authoritative information on this subject is available in the Federal Highway Administration's *Traffic Analysis Toolbox*. Four volumes of the *Toolbox* provide general guidance on the use of traffic analysis tools, including the HCM:

A useful reference on traffic operations modeling is the Federal Highway Administration's Traffic Analysis Toolbox.

- *Volume I: Traffic Analysis Tools Primer* (*1*) presents a high-level overview of the different types of traffic analysis tools and their role in transportation analyses.
- *Volume II: Decision Support Methodology for Selecting Traffic Analysis Tools* (*2*) identifies key criteria and circumstances to consider in selecting the most appropriate type of traffic analysis tool for the analysis at hand.
- *Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software* (*3*) provides a recommended process for using traffic microsimulation software in traffic analyses.
- *Volume VI: Definition, Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness* (*4*) describes the appropriate definition, interpretation, and computation of MOEs for traffic operations and capacity improvements. This report provides information and guidance on which MOEs should be produced, how they should be interpreted, and how they are defined and calculated in traffic analysis tools. The document recommends a basic set of MOEs that can help rapidly assess the current problems and the benefits of alternative improvements at the system level, in a form readily understandable by the decision maker.

Other volumes of the *Toolbox* deal with the application of alternative tools for specific application scenarios.

The material in this section focuses primarily on the automobile mode. The importance of other modes—particularly bicycles, pedestrians, and transit—is recognized; however, experience with the use of alternative tools to address these modes is limited. Some alternative tools address nonautomobile modes explicitly and some do not. The *Traffic Analysis Toolbox* (*1*–*3*) mentions the inability to deal with "interferences that can occur between bicycles, pedestrians, and vehicles sharing the same roadway" as a limitation of most simulation tools. Where appropriate, specific guidance is presented on the treatment of bicycles, pedestrians, and buses in the chapters of Volumes 2 and 3. The best source of guidance for the use of alternative tools for other modes is the detailed documentation and user's guide provided with tools that offer these features.

TRAFFIC MODELING CONCEPTS AND TERMINOLOGY

Hierarchy of Modeling Terminology

Modeling terminology has not been applied consistently throughout the realm of traffic analysis tools. For purposes of the HCM, the following terminology will be used to distinguish between different objects and processes that have been referred to in the literature simply as a "model":

- An *algorithm* is, by dictionary definition (*5*), "a set of rules for solving a problem in a finite number of steps." This definition suits the HCM's purposes.
- A *model* is, by dictionary definition (*5*), "a hypothetical description of a complex entity or process." Here is the root of the inconsistent usage. By this definition the word can be, and has been, applied to many different objects. A more focused definition is required. One definition in common use is that a model is "a representation of a system that allows for investigation of the properties of the system and, in some cases, prediction of future outcomes"(*6*). For HCM purposes, the term will be used in this sense but will be more precisely defined as "a procedure that uses one or more algorithms to produce a set of numerical outputs describing the operation of a highway segment or system, given a set of numerical inputs." By this definition, each of the performance analysis procedures specified in Volumes 2 and 3 constitutes a model. This term will generally be used with an adjective to denote its purpose (e.g., delay model).
- A *computational engine* is the software implementation of one or more models that produces specific outputs given a set of input data.
- A *traffic analysis tool,* often abbreviated in the HCM as a "tool," is a software product that includes, at a minimum, a computational engine and a user interface. The purpose of the user interface is to facilitate the process of entering the input data and interpreting the results.
- A *model application*, sometimes referred to as a *scenario,* specifies the physical configuration and operational conditions to which a traffic analysis tool is applied.

Inconsistency in terminology arises because each of these five objects has been characterized as a model in the literature, since each one satisfies the dictionary definition. The distinction between the five terms is made here in the hope of promoting more consistent usage.

Additional Modeling Definitions

Another set of terminology that requires more precise definitions deals with the process by which the analyst ensures that the modeling results provide a realistic representation of the real world. The following terms are defined elsewhere (*3*):

- *Verification:* The process by which the software developer and other researchers check the accuracy of the software implementation of traffic operations theory. The extent to which a given tool has been verified is listed as an important tool selection criterion in this chapter.
- *Calibration*: The process by which the analyst selects the model parameters that cause the model to best reproduce field-measured local traffic conditions.
- *Validation:* The process by which the analyst checks the overall model-predicted traffic performance for a street–road system against field measurements of traffic performance, such as traffic volumes, travel times, average speeds, and average delays. Model validation is performed on the basis of field data not used in the calibration process.

Traffic Analysis Tool and Model Categories

The *Traffic Analysis Toolbox* identifies the following categories of traffic analysis models:

- *Sketch-planning tools* produce general order-of-magnitude estimates of travel demand and transportation system performance under different transportation system improvement alternatives.
- *Travel demand models* forecast long-term future travel demand on the basis of current conditions and projections of socioeconomic characteristics and changes in transportation system design.
- *HCM-based analytical deterministic tools* quickly predict capacity, density, speed, delay, and queuing on a variety of transportation facilities.
- *Traffic signal optimization tools* are primarily designed to develop optimal signal phasing and timing plans for isolated signalized intersections, arterial streets, or signal networks.
- *Macroscopic simulation models* are based on the deterministic relationships of the flow, speed, and density of the traffic stream.
- *Microscopic simulation models* simulate the movement of individual vehicles on the basis of car-following and lane-changing theories.
- *Mesoscopic models* combine the properties of microscopic and macroscopic simulation models.
- *Hybrid models* employ microscopic and mesoscopic models simultaneously. These tools are intended to be applied to very large networks containing critical subnetworks connected by several miles of essentially rural facilities. Microscopic modeling is applied to the critical subnetworks, while the connecting facilities are modeled at the

Hybrid models, used with very large networks, apply microscopic modeling to critical subnetworks and mesoscopic or macroscopic modeling to the connecting facilities.

mesoscopic or macroscopic level. Regional evacuation models are a typical example of hybrid model application.

Stochastic and Deterministic Models

The HCM's methodologies are deterministic—given the same set of inputs, the methods will produce the same result each time.

Most simulation models are stochastic—given identical inputs but a different random number seed, model runs will produce different results.

A *deterministic* model is not subject to randomness. Each model run will produce the same outcome. If these statements are not true and some attribute of the model is not known with certainty, the model is *stochastic*. Random variables will be used to represent those attributes of the model not known with certainty. Descriptions of how these random numbers are selected to obtain sample values of the parameter of interest (i.e., from its cumulative distribution function) can be found in various texts (e.g., *7–10*). Different random number sequences will produce different model results; therefore, the outcome from a simulation tool based on a stochastic model cannot be predicted with certainty before analysis begins. Stochastic models aid the user in incorporating variability and uncertainty into the analysis.

Static Flow and Time-Varying Flow Models

In static-flow models, users provide a single set of flow rates. The model may vary headways, but the O-D matrix is fixed and does not change throughout the duration of the analysis.

Time-varying models allow flow rates to change with time. Users supply more than one set of flow rates so that the O-D matrix can vary over time. Most models change flows once an hour, but some allow more frequent changes.

The terms *static flow* and *time-varying flow* relate to the temporal characteristics of the traffic flows in the simulation model. Basically, the terms differentiate between a model that uses constant traffic flow rates from one time period to another and a model that does not. This differentiation is not to be confused with whether the model can represent internally time-varying flows that occur because of simulated events (e.g., incidents, signal cycling, ramp metering, high-occupancy-vehicle lane closures). The difference is in the type of input flows that can be specified.

In the static flow case, traffic flows are provided just once, as a set of constants. A tool may vary the individual headways stochastically, but the flow rates are fixed. Put another way, the origin–destination (O-D) matrix is fixed and does not change throughout the duration of the analysis.

In the time-varying case, flow rates can change with time. More than one set of flow rates must be specified so that the O-D matrix can vary over time. The flexibility of specifying more than one set of flow rates is particularly useful when major surges in traffic need to be examined, such as the ending of a special event or peak periods when a pronounced variation in traffic flows exists.

Descriptive and Normative Models

Descriptive models show how events unfold given a logic that describes how the objects involved will behave.

Normative models try to identify a set of parameters that provide the best system performance.

The terms *descriptive* and *normative* refer to the objective of performing the analysis with simulation models. If the objective of the model is to describe how traffic will behave in a given situation, the model is most likely to be descriptive. It will not try to identify a given set of parameters that provide the best system performance but rather will show how events will unfold given a logic that describes how the objects involved will behave. For example, a simulation model could predict how drivers will behave in response to traffic flow conditions. A model attempting to shape that behavior by trying to force drivers to maintain specific headways would not be a descriptive model.

Normative models try to identify a set of parameters providing the best system performance. An external influence (most often referred to as an objective function) tries to force the system to behave in some optimal way. A good example is a model that tries to optimize signal timings. Another illustration is a freeway network model that requires drivers to alter their path choices to optimize some measure of system performance. In both cases, the behavior of the system is modified through an external influence, probably on an iterative basis, to create a sequence of realizations in which the objective function value is improved, as in minimizing total travel time or total system delay.

The distinction can be restated this way: if the model has an objective and seeks to optimize that objective, it is a normative model. Conversely, if it has an objective but does not seek to optimize that objective by changing the design or operational parameters (e.g., signal timing), it is a descriptive model.

Traffic assignment models are a special case, because they are based on an objective that is gradually improved over a sequence of iterations. In this case, the objective is for each driver to minimize either the travel time for the trip or some other quantitative measure of the general cost or disutility associated with the trip. Traffic assignment models are characterized as either *static* or *dynamic,* depending on whether the O-D characteristics are constant or time-varying. Most simulation tools have some form of dynamic traffic assignment (DTA). Because of its demands on computer resources, DTA is often implemented at the mesoscopic level. DTA models are often embedded in traffic microsimulation tools.

DTA models are a special case of descriptive models that are based on an objective (minimize the travel time or disutility associated with a trip) that is gradually improved over a sequence of iterations until the network reaches a state of equilibrium.

The optimization process may be characterized as either *system-optimal* or *user-optimal.* A user-optimal solution does not necessarily produce an optimal result for the system as a whole and vice versa. With user-optimal models, the objective being applied reflects a behavioral assumption, and therefore the model is primarily descriptive. System-optimal models enforce some changes in driver behavior and are therefore normative. The formulation of the generalized cost (disutility) function can be expanded to reflect actual driving behavior more accurately—for example, by taking into account the number of stops or the driver's familiarity with typical traffic conditions.

The important point is that the analyst needs to know which type of model is being used and how that type influences the model's predictions. For example, assume that the analyst is dealing with a scenario in which the signal timing is fixed and drivers can alter their path choices in response to those signal timings (in a way that replicates how they would actually behave). This is a descriptive model and is a common application of a DTA model as mentioned above. Even though the analyst can change the signal timings and see how the drivers respond (and how the system performance changes), the model is still describing how the system would behave for a given set of conditions. On the other hand, if the analyst alters the scenario so that it seeks a better set of signal timings, a normative model has been created.

A descriptive model is implied if the analyst introduces a new demand–supply paradigm, such as congestion pricing, based on a field study. A new demand-side routine could be developed to predict how drivers alter path choices in response to congestion prices, and a supply-side routine could be developed that seeks to set those prices in some responsive and responsible way in an effort to produce a desirable flow pattern. Even though two competing optimization schemes are at work, each describes how a portion of the system is behaving in response to inputs received. There is no explicit intent to optimize the system performance in a specific manner.

CONCEPTUAL DIFFERENCES BETWEEN DETERMINISTIC AND SIMULATION TOOLS

There are some conceptual differences between the HCM's analytical modeling and simulation modeling. It is useful to examine these differences before addressing alternative tool applications. Most of the differences may be described in terms of the way analytical and simulation tools deal with various traffic flow phenomena. Examples of the significant differences are identified in general terms in Exhibit 6-1.

APPROPRIATE USE OF ALTERNATIVE TOOLS

Situations when alternative tools might supplement HCM procedures.

Using alternative tools to supplement HCM capacity and quality-of-service procedures should be considered when one or more of these conditions apply:

- The configuration of the facility has elements that are beyond the scope of the HCM procedures. Each procedural chapter identifies the specific limitations of its own methodology.
- Viable alternatives being considered in the study require the application of an alternative tool to make a more informed decision.
- The measures produced by alternative tools are compatible with corresponding HCM measures and are arguably more credible than the HCM measures.
- The measures are compatible with corresponding HCM measures and are a by-product of another task, such as optimization of a network traffic control system.
- The measures are compatible with corresponding HCM measures and the decision process requires additional performance measures, such as fuel consumption and emissions, which are beyond the scope of the HCM.
- The system under study involves a group of different facilities or travel modes with mutual interactions invoking several procedural chapters of the HCM. Alternative tools are able to analyze these facilities as a single system.
- Routing is an essential part of the problem being addressed.
- The quantity of input or output data required presents an intractable problem for the HCM procedures.
- The HCM procedures predict oversaturated conditions that last throughout a substantial part of a peak period or queues that overflow the available storage space, or both.

Exhibit 6-1
Comparison of Methods for Addressing Traffic Phenomena by the HCM and Typical Microsimulation Tools

Traffic Phenomenon	Deterministic (HCM) Treatment	Typical Microsimulation Treatment
Right turn on red	Subtract right-turn-on-red volume from demand	Microscopic model of gap acceptance and follow-up time
Permitted left turns	Empirical model of capacity versus opposing volume, with minimum capacity determined by an assumption of two sneakers per cycle	Microscopic model of gap acceptance and follow-up time
STOP sign entry	Macroscopic model of gap acceptance and follow-up time	Microscopic model of gap acceptance and follow-up time
Channelized right turns	Subtract right-turning volume from demand	Microscopic model of gap acceptance and follow-up time; implicit effects of right-turn queues
Ramp merging	Empirical model of merge capacity versus freeway volume in the two outside lanes	Microscopic model of gap acceptance and follow-up time (some tools incorporate cooperative merging features)
Merging during congested conditions	Not addressed	Microscopic model of gap acceptance
Lane-changing behavior	Macroscopic model based on demand volumes and geometrics	Microscopic model of lane-changing behavior
Queue start-up on green	Fixed start-up lost time subtracted from the displayed green time	Stochastic lost time applied to the first few vehicles in the departing queue
Response to change interval	Fixed extension of green time added to the displayed green time	Kinematic model of stopping probability
Actuated signal operation	Deterministic model for computing green times as a function of demand and operating parameters	Embedded logic emulates traffic-actuated control explicitly; tools vary in the level of emulation detail
Delay accumulation	Analytical formulation for uniform delay based on the assumption of uniform arrivals over the cycle and uniform departures over the effective green	These three effects are combined implicitly in the accumulation and discharge of individual vehicles over the analysis period
Progression quality	Adjustment factor applied to the uniform delay term	
Random arrivals	Analytical formulation for incremental delay	
Generation of vehicles	Incremental delay formulation assumes Poisson arrivals (mean = variance) at the stop line; the variance–mean ratio is reduced for traffic-actuated control as a function of the unit extension	Individual vehicles are introduced into entry links randomly, on the basis of a specified distribution
Effect of oversaturation	A third analytical formulation, d_3, is introduced to cover the additional delay due to an initial queue	Oversaturated operation and residual queues are accounted for implicitly in the accumulation and discharge of individual vehicles
Residual queue at the end of analysis period	Analytical formulation computes the residual queue when $d/c > 1.0$; the residual queue from one period becomes the initial queue for the next period	

In addition, when a specific HCM procedure has been developed by using simulation results as a surrogate for field data collection, it might be appropriate to use the underlying simulation tool directly to deal with complex configurations that are not covered in the HCM.

The following are factors to consider in the decision to use an alternative tool:

- Is the use of the alternative tool acceptable to the agency responsible for approving the decisions that result from its use?
- Are the necessary resources, time, and expertise available to apply the alternative tool?
- Does the application rely on a traceable and reproducible methodology?
- Have assumptions used to apply the tool been sufficiently documented?
- Is sufficient time available for calibration to promote a robust reliance on the model output?
- Are sufficient and appropriate data available to capitalize on or leverage the strength of the alternative tool?
- Are the alternative tool's performance measures (output) defined and computed in a manner consistent with the specification given in Chapter 7, Interpreting HCM and Alternative Tool Results?

Exhibit 6-2 provides examples of typical alternative tool applications for various situations that occur with both interrupted- and uninterrupted-flow conditions. Corridor and areawide analyses are also addressed in this exhibit. HCM procedures, which focus on points on the roadway and on linear roadway systems, tend to have limitations that are best addressed by tools that explicitly model corridors and areawide transportation systems.

For corridor and areawide analysis, aggregation of the results from Volume 2 and Volume 3 procedures require an intractable amount of data and effort. The interaction between individual facilities cannot be accounted for by HCM procedures. DTA might be required to balance flows among facilities and to model congestion propagation through the network due to oversaturation. Examples of promising alternative tool applications include active traffic management (ATM), congestion pricing, and freight corridors.

Alternative tool applications may be most appropriate for the evaluation of ATM measures that address operating conditions not explicitly addressed by HCM procedures. ATM consists of the dynamic and continuous monitoring and control of traffic operations on a facility. Examples of ATM measures include congestion pricing, managed lanes, ramp metering, changeable message signs, incident response, and speed harmonization (variable speed limits).

More information on ATM measures and their evaluation can be found in Chapter 35, Active Traffic Management.

ATM measures, because of their dynamic nature, cannot be adequately modeled with HCM procedures. HCM procedures assume steady-state demand and control conditions within the typical minimum 15-min analysis period. Alternative tool applications that model traffic operations and interactions with traffic controls at the minute-by-minute level will be more accurate than HCM procedures that model operations at the higher level of temporal aggregation.

Exhibit 6-2
Typical Applications for Alternative Traffic Analysis Tools

HCM Chapter	Typical Alternative Tool Application
Typical Applications in Volume 2: Uninterrupted Flow	
Applicable to all uninterrupted-flow procedures	Bottlenecks Oversaturated flow analysis Time-varying demands Unbalanced lane use Special lane restrictions Surveillance, work zones
10: Freeway Facilities	Managed lanes Surface street traffic control and ramp metering
11: Basic Freeway Segments	See uninterrupted-flow situations above
12: Freeway Weaving Segments	Complex weaving areas
13: Freeway Merge and Diverge Segments	Ramp metering High-occupancy-vehicle ramp lanes
14: Multilane Highways	See uninterrupted-flow situations above
15: Two-Lane Highways	Combination of terrain and traffic characteristics such as power–weight ratios or coefficient of variation of desired speeds
Typical Applications in Volume 3: Interrupted Flow	
Applicable to all interrupted-flow procedures	Oversaturated flow analysis (except for signalized intersections) Bus activity On-street parking Special lane use Queue spillback Pedestrian–bicycle interactions
16: Urban Street Facilities	Multimodal system analysis
17: Urban Street Segments	Mix of signals and no signals (stop and yield) Effects of midblock bottlenecks Signal timing plan development Turn bay overflow
18: Signalized Intersections	Geometrically offset intersections Alternative arrival characteristics Phase skips Pedestrian actuation Timing plan development
19: Two-Way STOP-Controlled Intersections	Two-way left turns Yield-controlled intersection delay TWSC intersection on a signalized arterial
20: All-Way STOP-Controlled Intersections	AWSC intersection on a signalized arterial
21: Roundabouts	Roundabout on a signalized arterial Multilane roundabouts Effect of geometrics Mixed-mode traffic
22: Interchange Ramp Terminals	Full cloverleaf interchange Backup from freeway segments Long-term (i.e., multicycle) blockage of approaches
23: Off-Street Pedestrian and Bicycle Facilities	Explicit modeling of pedestrian crossing activity

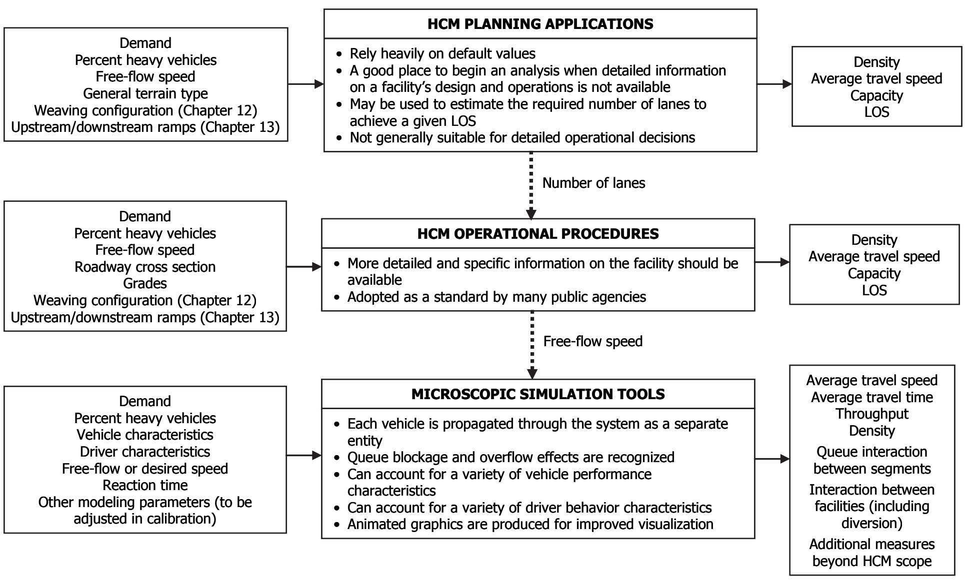
APPLICATION FRAMEWORK FOR ALTERNATIVE TOOLS

A wide range of tools is available for application to most highway capacity and performance analysis situations. Each tool has certain inputs and outputs, some of which can support a productive flow of information between tools. This section discusses the classes of tools that are available to address different types of system elements and suggests a framework for their application. Since the application framework differs among system elements, each element will be discussed separately. In developing input data for all these elements, it is important to reflect local default values.

Freeways

The modeling framework for freeways is presented in Exhibit 6-3. Each of the tools and procedures can be used in a stand-alone fashion; the potential flow of information between them indicates how they might fit into an overall analysis structure.

Exhibit 6-3
Freeway Modeling Framework for the HCM and Alternative Tools



Tools available for modeling freeways include HCM planning procedures, HCM operational procedures, and microscopic simulation.

Alternative tools find a much stronger application to freeway facilities than to individual freeway segments.

The principal classes of tools are

- The HCM planning applications, which rely heavily on default values for parameters;
- The HCM operational applications that require more detailed inputs in place of the default parameter values; and
- Microscopic simulation tools, as described previously in this chapter.

Most HCM freeway analysis limitations are apparent when the freeway is analyzed as a facility consisting of multiple segments of different types (basic segments, ramps, weaving segments, etc.) by using the procedures given in Chapter 10, Freeway Facilities. Alternative tools, especially microsimulation tools, find a much stronger application to freeway facilities than to individual segments.

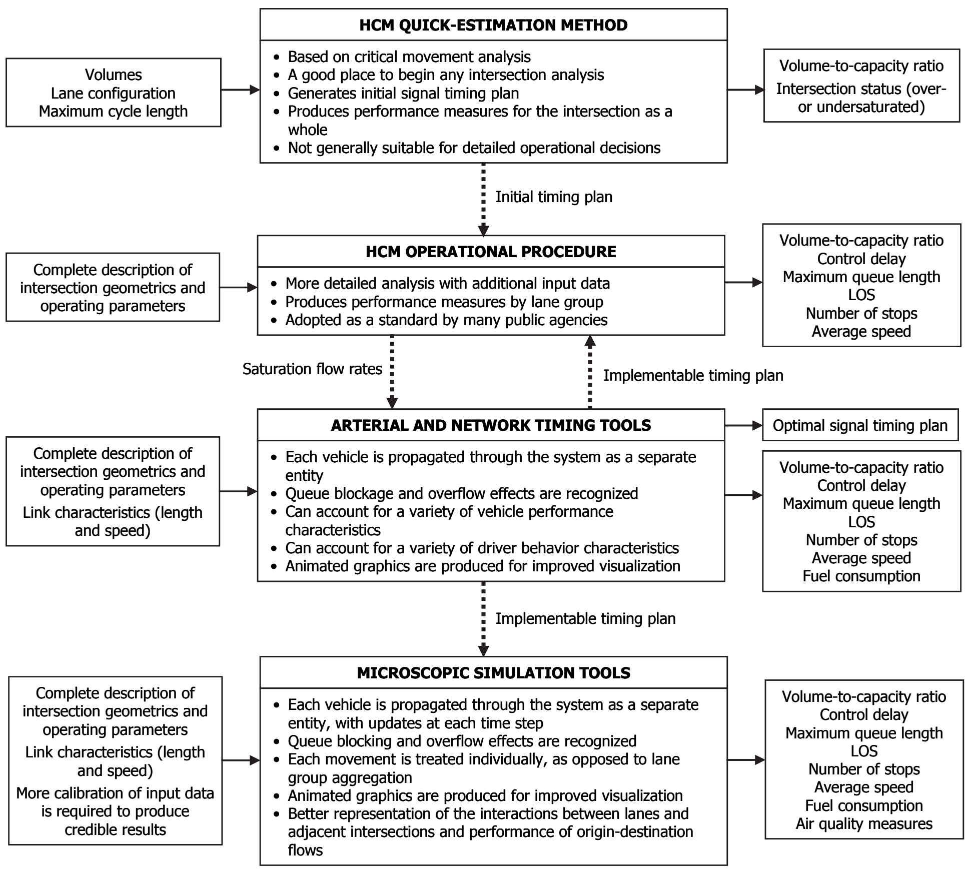
Urban Streets

Tools available for modeling urban streets include the HCM quick-estimation method for signalized intersections, HCM operational methods, arterial and network signal-timing tools, and microscopic simulation.

The modeling framework for urban streets, including their intersections, is presented in Exhibit 6-4. Each of the tools and procedures can be used in a stand-alone fashion; the potential flow of information between them indicates how they might fit into an overall analysis structure. The principal classes of tools are

- The HCM quick-estimation method for signalized intersections, which is based primarily on critical movement analysis and default values;
- The HCM operational methods for urban streets, including all types of intersections, which require more detailed traffic inputs and operating parameters;
- Arterial and network signal-timing tools, which produce recommended signal-timing plans based on measures that are generally similar to those produced by the HCM procedures; and
- Microscopic simulation tools, as described previously in this chapter.

Exhibit 6-4
Urban Street Modeling Framework for the HCM and Alternative Tools



Source: *Signalized Intersections: Informational Guide* (*11*).

Signal-timing tools generate signal-timing plans that can be used as inputs to HCM operational methods or to microsimulation tools.

Signal-timing tools are mostly based on macroscopic analytical models of traffic flow. Because they are the only class of urban street analysis tool that generates a signal-timing plan design, they are frequently used as an alternative tool for this purpose. The signal-timing plan may be fed into the HCM operational analysis or used as input to a microsimulation tool.

Microsimulation tools are used in urban street analysis, mainly to deal with complex intersection phenomena beyond the limitations of the HCM. These tools evaluate interactions between arterial segments, including the effect of various types of unsignalized intersections. They are also applied in evaluating networks and corridors with parallel facilities with the use of DTA routines.

Microsimulation tools are used to deal with complex intersection interactions beyond the limitations of the HCM.

Two-Lane and Multilane Highways

At this point, there is minimal application of alternative tools for the analysis of either type of highway. The HCM is the only macroscopic deterministic tool in common use, although some states such as Florida have developed their own analysis tools that implement derivatives of HCM procedures (*12*). At the time of writing, microsimulation models were in various stages of development. Some two-lane highway simulation tools were beginning to emerge, but there was insufficient experience to provide guidance for their use as an alternative to the methodology provided here.

At the time of writing, the HCM was the only deterministic tool in common use for two-lane and multilane highways.

Corridor and Areawide Analysis

Corridor and areawide analysis is an important application for alternative tools. The HCM procedures deal mainly with points and segments and are limited in their ability to recognize the interaction between segments and facilities. The overall modeling framework for corridor and areawide analysis is presented in Exhibit 6-5, which shows the relationship of the HCM to the broad field of corridor and areawide analysis models.

Corridor and areawide analysis is probably the most important application for alternative tools.

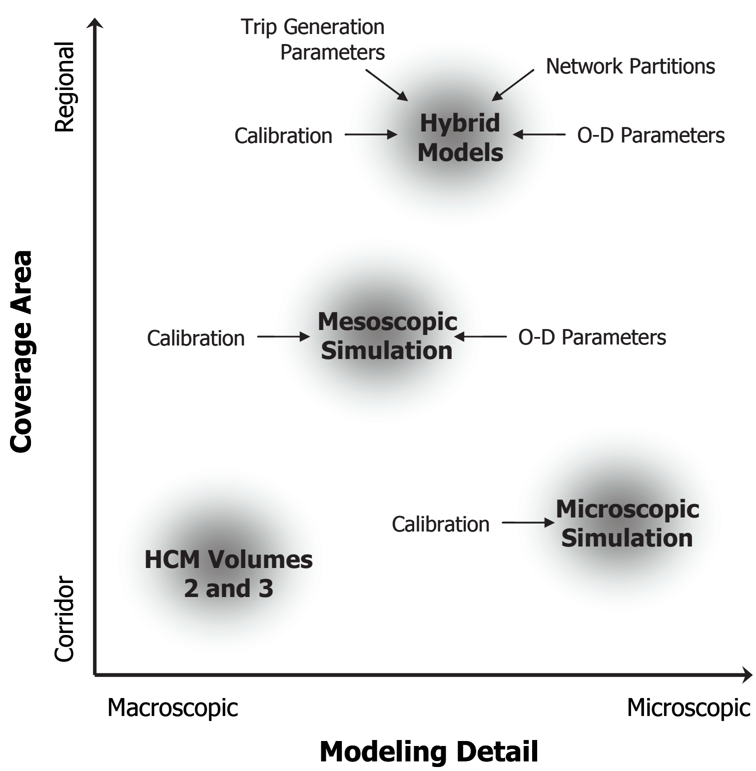


Exhibit 6-5
Corridor and Areawide Analysis Modeling Framework for the HCM and Alternative Tools

An excellent reference for corridor and areawide simulation (*13*) is emerging from a U.S. Department of Transportation research initiative on integrated corridor modeling, providing detailed guidance on the conduct of large-scale simulation projects. This section presents an overview of corridor and areawide simulation from the perspective of HCM users, but considerably more detailed information is presented in the report (*13*), including a more detailed analysis framework.

The framework for corridor and areawide analysis differs from the framework presented for freeways and urban streets in three ways:

1. The HCM procedures account for a much smaller part of the modeling framework.
2. Different levels of simulation modeling are represented here. Simulation of urban streets and freeways is typically performed only at the microscopic level.
3. The framework is two-dimensional, with the coverage area as one dimension and the modeling detail as the other.

The selection of a model class (microscopic, mesoscopic, or hybrid) reflects a trade-off between coverage area and modeling detail.

The various model classes shown in Exhibit 6-5 depict the trade-off between these characteristics. The trade-off between coverage area and modeling detail is evident:

- Microscopic simulation provides more detail and more coverage than the HCM procedures. The additional detail comes from the microscopic nature of the model structure. The additional coverage comes from the ability to accommodate multiple links and nodes.
- Mesoscopic simulation provides more coverage with less modeling detail than microscopic simulation. In addition to accommodating larger areas, mesoscopic models are computationally faster than microscopic models and are thus well suited to the iterative simulations required for DTA, which can be time-consuming.
- Hybrid modeling uses network partitioning to treat more critical parts of the system microscopically and less critical parts mesoscopically—or even macroscopically. In this way, the regional coverage may be expanded without losing essential detail. A typical application for hybrid modeling might be interurban evacuation analysis, which must accommodate a very large geographical area without loss of detail at critical intersections and interchanges.

Some examples of corridor modeling are presented in Volume 4 of the HCM.

PERFORMANCE MEASURES FROM ALTERNATIVE TOOLS

The tool selected for a given analysis needs to provide performance measures that realistically reflect the attributes of the problem being studied.

Before the analyst can select the appropriate tool, the performance measures that realistically reflect attributes of the problem under study must be identified. For example, when oversaturated conditions are studied, it is necessary to use a tool that quantifies the effects of queuing as well as stops and delay. If the methodologies presented in Volumes 2 and 3 do not provide a particular performance measure of interest to the analyst (e.g., fuel consumption and emissions), an alternative tool might be required. Exhibit 6-6 provides a summary of important performance measures for the procedures discussed in Volumes 2 and 3. The applicability of the HCM procedures and alternative tools is indicated for each chapter in this exhibit.

Exhibit 6-6
Principal Performance Measures from the HCM and Alternative Tools

Uninterrupted-Flow Chapters (Volume 2)								
HCM Chapter	**Speed**	**Delay**	**Through-put**	**Density**	**% Time Spent Following**	**Passing/ Overtaking**	**Environ-mental**	**Demand/ Capacity**
10. Freeway Facilities	H, A	H, A	H, A	H, A	X	X	H	X
11. Basic Freeway Segments	H, A	A	H, A	H, A	X	X	A	H
12. Freeway Weaving Segments	H, A	A	H, A	H, A	X	X	A	H
13. Freeway Merge and Diverge Segments	H, A	A	H, A	H, A	X	X	A	H
14. Multilane Highways	H, A	A	H, A	H, A	X	X	A	H
15. Two-Lane Highways	H, A	H	H	A	H	H, A	A	H
Interrupted-Flow Chapters (Volume 3)								
HCM Chapter	**Delay**	**Stops**	**Through-put**	**Queue Length**	**Cycle Failure**	**Environ-mental**	**Speed**	**Demand/ Capacity**
16. Urban Street Facilities	H, A	A	H, A	H, A	A	A	H, A	H
17. Urban Street Segments	H, A	A	H, A	H, A	A	A	H, A	H
18. Signalized Intersections	H, A	A	H, A	H, A	A	A	X	H
19. TWSC Intersections	H, A	A	H, A	H, A	X	A	A	H
20. AWSC Intersections	H, A	A	H, A	H, A	X	A	A	H
21. Roundabouts	H, A	A	H, A	H, A	X	A	A	H
22. Interchange Ramp Terminals	H, A	A	H, A	H, A	A	A	X	H
23. Off-Street Pedestrian and Bicycle Facilities	X	X	X	X	X	X	H	H (pedestrian)

Notes: Applicability codes:
- H: Performance measures computed by the HCM and some deterministic tools with similar computational structures.
- A: Performance measures computed by alternative tools (mostly simulation-based).
- X: Performance measures do not apply to this chapter.

TWSC: Two-way STOP-controlled. AWSC: All-way STOP-controlled.
Source: Adapted from Dowling et al. (*3*).

If an alternative tool is used to analyze highway capacity and quality of service, then the performance measures generated by the tool should, to the extent possible, be compatible with those prescribed by the HCM. Alternative tools frequently apply the same terminology to performance measures as the HCM, but divergent results are often obtained from different tools because of differences in definitions and computational methods. General guidance on reconciling performance measures is given in Chapter 7, Interpreting HCM and Alternative Tool Results. More specific guidance on dealing with performance measures from alternative tools is given in several of the procedural chapters in Volumes 2 and 3.

When an alternative tool is used to analyze highway capacity and quality of service, its performance measures should ideally be compatible with those prescribed by the HCM. Chapter 7 provides general guidance on this topic, while selected chapters in Volumes 2 and 3 provide specific guidance for certain system elements.

TRAFFIC ANALYSIS TOOL SELECTION CRITERIA

The success of a traffic analysis project depends on the selection of the best tool or tools for the purpose, followed by the proper application of the selected tools. Both of these issues are addressed in detail in the *Traffic Analysis Toolbox*, and the guidance provided in the *Toolbox* should be studied thoroughly before a major traffic analysis project is undertaken.

Determining Project Scope

A properly defined problem and project scope are essential prerequisites to the correct selection of tools or procedures for the project. Answers to the following questions will assist in scoping the project:

Questions to ask during the scoping of a traffic analysis project.

1. What is the operational performance problem or goal of the study?
2. Does the network being studied include urban streets, freeways, rural highways, or any combination of them?
3. Are multiple routes available to drivers?
4. What are the size and topology (isolated junctions, linear arterial, grid) of the network?
5. What types of roadway users (cars, carpools, public transit vehicles, trucks, bicycles, pedestrians) should be considered?
6. What traffic control methods (regulatory signs, pretimed signals, actuated signals, real-time traffic-adaptive signals, and ramp-metering signals) should be considered?
7. Should oversaturated traffic conditions be considered?
8. Does the network involve specialized traffic control or intelligent transportation system (ITS) features that are not covered by the HCM?
9. What is the duration of the analysis period?
10. Do the geometric conditions of the roadway facility change during the analysis period?
11. Does the traffic demand fluctuate significantly during the analysis period?
12. Does the traffic control change during the analysis period?
13. What output and level of detail are anticipated from the tool?
14. What information is available for model input, model calibration, and validation?
15. Are multiple methods available for consideration in the analysis?

Assessing HCM Methodologies

Use the Limitations of the Methodology and Special Cases sections of Volume 2 and 3 chapters to assess the appropriateness of the HCM methodology for a given analysis.

Another essential step in the analysis tool selection process is to assess the capability of the existing HCM methodologies and to determine whether these methodologies can be applied (in whole or in part) to the issues that were raised in the project-scoping step. In addressing these issues, two major questions should be answered: What are the limitations of the HCM methodologies? Can the limitations be overcome? Limitations of the existing HCM methodologies for each facility type are identified in the procedural chapters of Volumes 2 and 3 of this manual. If it is determined that an alternative tool is needed or advisable, then the most appropriate tool must be selected.

Selecting a Traffic Analysis Tool

Every traffic analysis tool, depending on the application, has its own strengths and weaknesses.

Each analytical or simulation model, depending on the application, has its own strengths and weaknesses. It is important to relate relevant model features to the needs of the analysis and determine which tool satisfies those needs to the greatest extent. Both deterministic and simulation-based tools could be candidates for overcoming HCM limitations. In most cases, however, deterministic tools will exhibit limitations similar to the HCM procedures, which are also deterministic. Deterministic tools also tend to work at the same macroscopic level as the HCM. The main applications for alternative deterministic tools fall into the following categories:

- Signal-timing plan design and optimization,
- Proprietary deterministic models that offer features not found in the HCM,
- Proprietary tools that exchange data with other traffic analysis software, and
- Roundabout analysis tools that deal with geometric and operational parameters beyond the scope of the HCM.

Simulation tools will generally be chosen to deal with situations that are too complex to model as a deterministic process. The balance of this discussion deals primarily with microscopic simulation tools.

Model Development Environment and Process

The manner in which the modeling logic was developed is an important consideration in the selection of a traffic analysis tool. The credibility of results from a simulation model depends on the process by which it was designed, implemented, and tested. A comprehensive document (*14*) describes "a formal process used to verify the model's reproducibility of traffic conditions in the development of a traffic flow simulation model." The intent is to prescribe a set of requirements to which all tools should conform. There is no attempt to compare the merits of different tools.

The proper simulation model development process is described in terms of the following steps. The desirable attributes of each of these steps are described:

- Determination of model specifications,
- Contrivance of the model operation principles,
- Programming and debugging,
- Verification using virtual data, and
- Verification using actual data.

The traffic phenomena to be modeled through simulation are identified, and the theoretical basis for dealing with each one in a traffic model is described:

- Generation of vehicles,
- Bottleneck capacity or saturation flow rate at a link's downstream end,
- Drawing and elimination of breakdown and shock wave propagation speed,
- Capacity of the merge/diverge area and the merge/diverge ratio,
- Decrease in the left-turn capacity due to opposing traffic in a signalized intersection, and
- Route selection behavior.

Users who are unfamiliar with the operation of their candidate simulation tools may wish to consult this document for informational purposes.

Key model features to consider.

Model Capabilities

A review of modeling capabilities is probably the most important aspect of selecting a simulation tool. Simulation model results may be of no value if the model is not capable of addressing the project-scoping issues raised in the initial step. Some key features can be used to evaluate a model's capabilities, such as size of network, network representation, traffic representation, traffic composition, traffic operations, traffic control, and model output.

- *Size of network.* Most tools limit the size of network that can be analyzed and the number of vehicles that can be accommodated. The key network parameters limited by the tool include number of nodes, number of links, number of lanes per link, and number of sign- or signal-controlled intersections.
- *Network representation.* Network representation refers to the tool's ability to represent the network geometries for urban streets, freeways, rural highways, or any combination, ranging from single intersections to grid networks. For urban streets, major geometric elements include lane channelization at intersections, turning pockets, and bus bays and stops. For freeways, major geometric elements are acceleration lanes, deceleration lanes, auxiliary lanes, on-ramps, off-ramps, lane additions, lane drops, horizontal curvature, and grade. Elements for rural highways include grade, curvature, passing and no-passing zones, and sight distance for overtaking and passing.
- *Traffic representation.* The representation of how traffic flows in the model, especially the level of aggregation, is an important consideration. Because of their microscopic and stochastic nature, microscopic models can simulate sophisticated vehicle movements, allowing analysts to perform complex traffic analyses such as those for weaving areas. In contrast, mesoscopic and macroscopic models are generally not appropriate for evaluating complex traffic conditions, since they use aggregate measures of flow or density to describe vehicle movements.
- *Traffic composition.* Traffic composition represents the mix of cars, buses, trucks, carpools, and bicycles in the network and is used to incorporate the differences in performance characteristics among types of vehicles and modes. Special attention needs to be given to the selection of the analysis tool when networks with dedicated accommodation for nonautomobile modes are involved.
- *Traffic operations.* The model should be capable of representing real-world traffic operations such as complex merging, diverging, and weaving maneuvers at interchanges, high-occupancy-vehicle lanes, bus transit operations, lane channelization at intersections, lane restrictions, lane blockages, and parking activities.
- *Traffic control.* For street intersections, control methods include YIELD signs, two-way STOP signs, all-way STOP signs, pretimed signals, actuated signals, real-time traffic-adaptive control signals, and traffic-responsive control systems. Those commonly used for freeway on-ramps include pretimed control, demand and capacity control, occupancy control, speed

control, high-occupancy-vehicle priority at ramps, integrated (areawide) ramp control, ramp-metering optimization, and dynamic real-time ramp-metering control with flow prediction capabilities. Signal coordination between traffic signals or between on-ramp signals and traffic signals on adjacent streets may also need to be considered.

- *DTA features.* When a network involves multiple routes that present a choice to the driver, the model must employ dynamic assignment logic to distribute the vehicles over the available paths in a realistic way. Simulation models offer varying degrees of DTA features and may allow for various influencing factors to be included in the decision process to reflect driver behavior. DTA models are discussed in more detail later in this chapter.
- *Other ITS devices.* In addition to the ITS elements in the traffic control category, tools may be able to model the effects of other ITS devices, such as in-vehicle navigation systems, dynamic message signs, incident management, smart work zones, or intervehicle communication technologies.
- *Real-time process control features.* Many tools offer the ability to communicate directly with other processes invoked in either hardware or software. Examples include intersection signal controllers and large-scale network traffic management systems. Most highway capacity analysis projects will not require features of this type. However, when complex networks with ITS elements are involved, the ability of a simulation tool to communicate directly with the outside world might become a significant factor in the selection of the proper tool.

Above all, the analyst should review the user's guide for the selected tool to get a more detailed description of its characteristics.

User Interface

User interface considerations.

The user interface includes all of the features of a tool that supply input data from the user to the model and output data from the model to the user. Simulation tools vary in the nature of their user interface. To some extent, the suitability of the user interface is a matter of individual preference. However, a highly developed user interface can offer a better level of productivity for larger and more repetitive tasks. Selection criteria related to the user interface include

- The amount of training needed to master its operation,
- The extent to which it contributes to productive model runs,
- The extent to which it is able to import and export data between other processes and databases, and
- Special computational features that promote improved productivity.

The following are the principal elements associated with the user interface:

- *Inputs.* Most of the inputs required by the model will be in the form of data. In most cases, the input data will be entered manually. Most tools offer some level of graphic user interface to facilitate data entry. Some tools also offer features that import data directly from other sources.

- *Outputs.* Two types of outputs are available from simulation tools: graphics files and static performance measures. Graphics files provide graphics output, including animation, so that users can visually examine the simulation model results. Static performance measures provide output for numerical analysis. Both types of outputs may be presented directly to the user or stored in files or databases for postprocessing by other programs.
- *Multiple-run support*. The stochastic nature of simulation models requires multiple runs to obtain representative values of the performance measures. Chapter 7, Interpreting HCM and Alternative Tool Results, provides guidance on the number of runs required under specific conditions. The ability of a tool to support multiple runs is an important selection criterion. Multiple-run support includes processing functions that perform a specified number of runs automatically and postprocessing functions that accumulate the results from individual runs to provide average values and confidence intervals.

Data Availability

Consider the kind of data required and the availability of the data in selecting a tool.

The next criterion identifies data requirements and potential data sources so that the disparity between data needs and data availability can be identified. In general, microscopic models require more intensive and more detailed data than do mesoscopic and macroscopic models. Three different types of data are required to make the application of the traffic simulation model successful: data for model input, data for model calibration, and data for model validation.

Data for Model Input

The basic data items required to describe the network and the traffic conditions to be studied can be categorized into four major groups:

1. *Transportation network data.* Simulation tools incorporate their network representation into the user interface, and some differences are observed among different tools. Most simulation models use a link-based scheme in which links represent roadway segments that are connected in some manner. The required link data include endpoint coordinates, link length, number of lanes per link, lane additions, lane drops, turning pockets, lane channelization at intersections, grade, and horizontal curvature. The connector data describe the manner in which the links are connected, including the permissible traffic movements, type of control, and lane alignment.
2. *Traffic control and ITS data.* Detailed control data should be provided for all control points, such as street intersections or freeway on- and off-ramps. Sign controls include YIELD signs, two-way STOP signs, and all-way STOP signs. Signal controls include pretimed signals, actuated signals, or real-time traffic-adaptive signals. Ramp-metering control methods include all of the modes described earlier. Timing data are required for all signal controls. Detector data such as type and location of the detector are required for actuated and traffic-adaptive signals. Any special ITS

features involved in a project will create a need for additional data describing their parameters.

3. *Traffic operations data.* To represent the real-world traffic environment, most simulation tools take link-specific operations data as input, such as parameters that determine roadway capacity, lane use, lane restriction, desired free-flow speed, high-occupancy-vehicle lanes, parking activities, lane blockages, and bus transit operations.
4. *Traffic demand data.* Different tools may require traffic demand data in different formats. The most commonly used demand data are traffic demand at the network boundary or within the network, traffic turning percentages at intersections or freeway junctions, O-D trip tables, path-based trips between origins and destinations, and traffic composition.

Data for Model Calibration

Calibration adjusts a model's vehicle, driver, and other characteristics so that the model can realistically represent the traffic environment being analyzed.

Calibration was defined previously as the process by which the analyst selects the model parameters that cause the model to best reproduce field-measured local traffic operations conditions. Vehicle and driver characteristics, which may be site-specific and require calibration, are the key parameters. These data take the form of scalar elements and statistical distributions that are referenced by the model. In general, simulation models are developed and calibrated on the basis of limited site-specific data. The development data may not be transferable and therefore may not accurately represent the local situation. In that case, the model results should be interpreted with caution, and the default parameters that must be overridden to better reflect local conditions should be identified. Most simulation tools allow the analyst to override the default driver behavior data and vehicle data to better match local conditions, thereby allowing for model calibration. The calibration process should be documented, traceable, and reproducible to promote a robust analysis.

1. *Driver behavior data.* Driver behavior is not homogeneous, and thus different drivers may behave differently in the same traffic conditions. Most microscopic models represent stochastic or random driver behavior (from passive to aggressive drivers) by taking statistical distributions of behavior-related parameters such as desired free-flow speed, queue-discharge headway, modeling parameters for lane changing and car following, and driver response to advance information and warning signs.
2. *Vehicle data.* Vehicle data represent the characteristics and performance of the types of vehicles in the network. Different vehicle types (e.g., cars, buses, single-unit trucks, semitrailers) have different characteristics and performance attributes. They vary in terms of vehicle length, maximum acceleration, maximum deceleration, emissions rate, and fuel consumption rate. All traffic simulation tools provide default vehicle characteristics and performance data. These data need to be overridden only when the local vehicle data are known to be different from the default data provided by the tool or when the default values do not provide reasonable results.

Data Sources

Data collection is costly. Analysts should explore all possibilities to leverage previously collected data. The analyst should identify which data are currently available and which data need to be collected in the field. Most static network, traffic, and control data can be collected from local agencies. Such data include design drawings for geometries, signal-timing plans, actuated controller settings, traffic volume and patterns, traffic composition, and transit schedules.

Ease of Use

Simulation models use assumptions and complex theories to represent the real-world dynamic traffic environment. Therefore, an input–output graphical display and debugging tools that are easily understandable are important criteria to consider in selecting a tool. Although ease of use is important in a simulation tool, the fact that a particular tool is easy to use does not necessarily imply that it is the correct choice. The following five criteria can be considered in assessing the ease of use of a simulation tool:

- *Preprocessor:* input data handling (user-friendly preprocessor);
- *Postprocessor:* output file generation for subsequent analysis;
- *Graphics displays:* graphic output capabilities, both animated and static;
- *Online help:* quality of online help support; and
- *Calibration and validation:* ability to provide guidelines and data sets for calibration and validation.

Required Resources

The following issues with regard to resources should be addressed in selecting a traffic analysis tool:

- *Costs to run the tool.* Examples are costs for data collection and input preparation, hardware and software acquisition, and model use and maintenance.
- *Staff expertise.* Intelligent use of the tool is the key to success. The analyst should understand the theory behind the model to eliminate improper use and avoid unnecessary questions or problems during the course of the project.
- *Technical support.* Quality and timely support are important in the acquisition of a tool.

User Applications and Past Performance

Credibility and user acceptance of a tool are built on the tool's past applications and experiences. No tool is error-free when first released, and all require continuous maintenance as well as periodic enhancements.

Verification and Validation

It is important to assess how extensively a given model has been verified. In many cases, but not all, simulation models are also validated as part of the formulation and development process. Certainly those that have been validated are nominally better to use than those that have not been validated. Generally, models that have been in use for some time are likely to have been assessed and validated by various researchers or practitioners who are using them. It is useful to look for evidence of validation in professional journals and periodicals.

APPLICATION GUIDELINES FOR SIMULATION TOOLS

This section presents general guidance for the use of simulation-based traffic analysis tools for capacity and performance analysis. More detailed guidance for the application of these tools to specific facilities is presented in the procedural chapters of Volumes 2 and 3. Additional information, including sample applications, may be found in Volume 4 and in the *Traffic Analysis Toolbox* (*3*) mentioned earlier in this chapter.

After the project scope has been determined and the tool has been selected, several steps are involved in applying the tool to produce useful results.

Assembling Data

Data assembly involves collecting the data required (but not already available) for the selected tool. Data collection is costly. Analysts should capitalize on previous modeling efforts and identify data available through local agencies. When existing data are assembled, users should develop a comprehensive plan for collecting data that are missing. In some cases, a pilot data collection effort may be needed to ensure that the developed data collection plan is workable before a full-scale effort is conducted.

An important part of the data assembly process is a critical review of all data items to ensure the integrity of the input data set. Of special concern are the continuity of traffic volumes from segment to segment and the distribution of turning movements at intersections and ramp junctions. Each data item should be checked to ensure that its value lies within reasonable bounds.

Entering Data

Once all required data are in hand, the next step is to create the input files in a format required by the selected tool. The following are the most commonly used methods for creating input files:

- *Importing from a traffic database.* Many analysts have large amounts of data in a variety of formats for the general purpose of traffic analysis. Such databases can be used to create input files.
- *Converting from the existing data of other tools.* Many traffic models use the same or similar data for modeling purposes so that these data may be shared. Some traffic simulation tools are accompanied by utility programs that allow the user to convert data into input files required by other tools.
- *Entering the data from scratch.* Many traffic analysis tools have their own specific input data preprocessors, which aid the analyst with input data entry and review. These advanced features of the input data preprocessor eliminate cumbersome coding efforts. In addition, some input preprocessors include online help features.

Calibrating and Validating Models

The model should be run with the data set describing the existing network and traffic scenarios (i.e., the baseline case), and the simulation results should then be compared with the observed data collected in the field. The primary objective of this activity is to adjust the parameters in the model so that simulation results correspond to real-world situations.

Several critical issues must be addressed when an initial simulation model run is conducted for the baseline case. First, the model should be able to represent the initial state of the traffic environment before any statistics can be collected for analysis. Second, the time should be long enough to cover the entire analysis period. Third, if the model can handle time-varying input, the analyst should specify, to the extent possible, the dynamic input conditions that describe the traffic environment. For example, if 1 h of traffic is to be simulated, the analyst should always specify the variation in demand volumes over that hour at an appropriate level of detail rather than specifying average, constant values of volume.

Finally, the analyst should know how to interpret the simulation model results, draw inferences from them, and determine whether they constitute a reasonable and valid representation of the traffic environment. Given the complex processes taking place in the real-world traffic environment, the user must be alert to the possibilities that the model's features may be deficient in adequately representing some important process; that the specified input data, calibration, or both are inaccurate or inadequate; that the results provided are of insufficient detail to meet the project objectives; that the statistical analysis of the results is flawed (as discussed in the following section); or that the model has bugs or that some of its algorithms are incorrect, thereby necessitating revision. If animation displays are provided by the model, this option should always be exercised to identify any anomalies.

If the simulation model results do not reasonably match the observed data collected in the field, the user should identify the cause-and-effect relationships between the observed and simulated data and the calibration parameters and perform calibration and validation of the model. Information on calibration and validation of models may be found in the *Traffic Analysis Toolbox* (*1–3*) and in the references listed in Volume 4.

Special Considerations for DTA

The term "traffic assignment" traditionally refers to the process of computing path demands, or path input flows, given a network and an O-D demand matrix (trip table). In microscopic simulation models, this process is implemented as a route-choice model that is executed independently for each driver (vehicle) in the simulation. Using explicit routes to move vehicles through the simulation obviates the use of turning proportions at nodes. Routes and route flows may also be implicitly represented in a model by splitting rates, which are turning proportions at nodes by destination. Route flows can have a significant impact on model outputs such as LOS, since they play a key role in determining the local traffic demand on any given section of road.

Regardless of the implementation, traffic assignment is relevant whenever demand is defined in the form of an O-D matrix (static or time-varying) and multiple routes are available for some O-D pairs. It is particularly relevant when congestion affects the travel times on some of these routes. DTA produces time-varying path flows (or splitting rates) by using a dynamic traffic model that is either mesoscopic or microscopic. DTA models normally permit the demand matrix to be time-varying as well. The assignment model (routing decision) is based on a specific objective, which is predominantly the minimization of travel time, but will also take other factors such as travel cost (e.g., tolls or congestion pricing) and travel distance into consideration.

A fundamental issue concerning the role of travel time in route choice is that the actual travel time from origin to destination cannot be known in advance: it results from the collective route choices of all the drivers. Thus, the input to the routing decision (travel time) depends on the decision itself (route choice), forming a logical cycle. This type of problem can be solved with an iterative algorithm that repeats the simulation several (or many) times over, imitating the day-to-day learning process of drivers in the real world. At each iteration (or "day") the assignment is adjusted until the route-choice decisions are consistent with the experienced travel times: this is referred to as the user-optimal solution. In practice, an approximation to the user-optimal route flows is often determined by using a "one-pass" (noniterative) assignment in which drivers repeatedly reevaluate their routes during a single simulation run. The choice of method depends on network characteristics and modeling judgment.

The assignment (routing) component of a DTA model may be deterministic or stochastic in nature, independent of whether the traffic model is deterministic or stochastic. In general, both approaches can produce good results as long as they produce route choices that are consistent with the routing objective, for example, the minimization of generalized travel cost. The generalized cost is determined from the combination of a range of factors, such as travel time, travel distance, and direct costs (e.g., tolls), by applying relative weights to each of these factors, which typically differ by user class.

DTA applications are not trivial. Whereas single route applications are typically implemented by one analyst, DTA applications to large-scale systems are more likely to involve a team of analysts with a broader range of skills and experience. A comprehensive reference on DTA has been written by the Transportation Research Board's Committee on Network Modeling (*15*).

Analyzing Output

Proper output analysis is one of the most important aspects of any study using a simulation model. A variety of techniques are used, particularly for stochastic models, to arrive at inferences that are supportable by the output.

When the model is calibrated and validated, the user can conduct a statistical analysis of the simulation model results for the baseline case with calibrated parameters. If the selected simulation model is stochastic in nature, simulation model results produced by a single run of the model represent only point estimates in the sample population. Typical goals of data analysis using output from stochastic-model experiments are to present point estimates of the performance measures and to form confidence intervals around these estimates. Point estimates and confidence intervals for the performance measures can be obtained from a set of replications of the system by using independent random number streams. The analyst should refer to previous studies for details on the design and analysis of stochastic simulation models in the *Traffic Analysis Toolbox* (*1*–*3*) and in Volume 4 of the HCM.

Analyzing Alternatives

When satisfactory simulation model results are obtained from the baseline case, the user can prepare data sets for alternative cases by varying geometry, controls, and traffic demand. If the model is calibrated and validated on the basis of the observed data, values of the calibrated parameters should also be used in the alternatives analysis, assuming that driver behavior and vehicle characteristics in the baseline case are the same as those in the alternative cases.

Traffic simulation models produce a variety of performance measures for alternatives analysis. As discussed previously, the user should identify what model performance measures and level of detail are anticipated. These performance measures, such as travel time, delay, speed, and throughput, should be quantifiable for alternatives analysis. Some tools provide utility programs or postprocessors, which allow users to perform the analysis easily. If animation is provided by the tool, the user can gain insight into how each alternative performs and can conduct a side-by-side comparison graphically.

4. REFERENCES

Many of these references can be found in the Technical Reference Library in Volume 4.

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APPENDIX A: DEVELOPING LOCAL DEFAULT VALUES

A default value is a constant to be used in an equation as a substitute for a field-measured (or estimated) value. Default values can be used for input parameters or calibration factors. The value selected should represent a typical value for the conditions being analyzed. Default values are generally used for planning, preliminary engineering, or other applications of the HCM that do not require the accuracy provided by a detailed operational evaluation (*A-1*). They can be applied to any of the modes addressed by the HCM.

Default values are generally used for HCM applications that do not require the accuracy provided by a detailed operational evaluation.

Local default values can be developed by conducting measurements of "raw data" in the geographic area where the values are to be applied. Typically, default values are developed for roadway or traffic characteristics to identify typical conditions of input variables for planning or preliminary engineering analysis. Default values should not be applied for input variables that can significantly influence the analysis results. For interrupted-flow facilities, these sensitive input variables include peak hour factor, traffic signal density, and percent heavy vehicles. For uninterrupted-flow facilities, these sensitive input parameters include free-flow speed, peak hour factor, and specific grade. In developing generalized service volume tables for daily service volumes, the *K*- and *D*-factors selected must be consistent with measured local values.

Default values should not be applied for input variables that can significantly influence the analysis results.

When local default values are developed, the raw data should be collected during the same time periods that will be used for analysis—typically during weekday peak periods. In some cases, the peak 15-min period is recommended as the basis for computation of default values because this time period is most commonly used for capacity and LOS analysis.

Input parameters that describe the facility type, area type, terrain type, and geometric configuration (such as lane width, segment length, and interchange spacing) are readily available to the analyst. Default values for these parameters should not be used.

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This reference can be found in the Technical Reference Library in Volume 4.

APPENDIX B: DEVELOPING LOCAL SERVICE VOLUME TABLES

INTRODUCTION

This appendix focuses on the automobile mode. To the limited extent that modal demand is an input to nonautomobile modes' LOS procedures, this material could also be applied to nonautomobile modes.

As discussed in the body of this chapter, service volume tables can provide an analyst with an estimate of the maximum number of vehicles a system element can carry at a given LOS. The use of a service volume table is most appropriate in certain planning applications in which evaluation of every segment or node within a study area is not feasible. Once potential problem areas have been identified, other HCM tools can be used to perform more detailed analyses for just those locations of interest.

To develop a service volume table, the analyst needs to develop a default value for each of the input parameters. The choice of default value can have a significant impact on the resulting service volume for a given LOS. For this reason, great care should be used to develop default values that the analyst believes are most appropriate for the local condition. When results are particularly sensitive to a particular input parameter, a range of default values should be considered for that parameter. The application of sensitivity analyses is discussed in more detail in Chapter 7, Interpreting HCM and Alternative Tool Results.

A specific roadway's characteristics are unlikely to match exactly the default values used to generate a service volume table. Therefore, conclusions drawn from such tables should be considered to be rough approximations.

When the service volume table is applied, it is important to recognize that not all of the input parameters for the various roadway segments being evaluated are likely to match the default inputs. Accordingly, conclusions drawn from the application of service volume tables should be considered to be, and presented as, rough approximations.

TABLE CONSTRUCTION PROCESS

Service volume tables can be generated for a given system element by selecting appropriate input parameter values and applying software to back-solve for the maximum volume associated with a particular LOS. The procedure is as follows (*B-1*):

1. Determine all of the nonvolume default values to be used in developing the service volume table (e.g., number of lanes, peak hour factor, percentage of heavy vehicles, area type, *K*- and *D*-factors), in accordance with the guidance in Appendix A. Repeat the following steps for each system element and area category.
2. Identify the threshold value associated with the system element's MOE for LOS A by using the LOS exhibit in the Volume 2 or Volume 3 chapter that covers that system element. For example, a density of 11 pc/mi/ln is the maximum density for LOS A for a basic freeway segment.
3. Compute the MOE for a volume of 10 veh/h for an hourly volume table, or 100 veh/h for a daily volume table. If the result exceeds the LOS A threshold value, then LOS A is unachievable. Repeat Steps 2 and 3 for the next LOS (e.g., LOS B) until an achievable LOS is found, then continue with Step 4.

4. Adjust the input volume until the highest volume that achieves the LOS is found. Test volumes should be a multiple of at least 10 for hourly volume tables and a multiple of at least 100 for daily volume tables. If the table is being constructed by manually applying software, the analyst can observe how closely the MOE result is converging toward the LOS threshold value and can select a test volume for the next iteration accordingly. If the table generation function is being added to software, the automated method described below can be used to converge on the service volume progressively.
5. Identify the threshold value for the next LOS and repeat Steps 4 and 5 until threshold volumes (or unachievability) have been determined for each LOS.
6. If a daily volume table is being created, divide the identified hourly threshold volumes by the selected *K*- and *D*-factors and round down to a multiple of at least 100.
7. If desired, change the input value used for one of the input parameters (e.g., number of lanes) and repeat Steps 2 through 5 as many times as needed to develop service volumes for all desired combinations of input values.

The following is an automated method for finding threshold values:

1. Let the first achievable test volume be labeled Vol 1.
2. Select a second iteration volume (label this Vol 2) by doubling Vol 1.
3. Compute the MOE value for Vol 2.
4. If the resulting MOE value is lower than the LOS threshold, replace Vol 1 with Vol 2 and select a new Vol 2 with double the current Vol 2 value. Repeat Steps 3 and 4 until the MOE result is greater than the desired LOS threshold.
5. Use the bisection method described below (*B-1*) or another more efficient numerical method to converge on the service volume.
6. Compute the volume halfway between Vol 1 and Vol 2. Label this volume Vol 3.
7. Compute the MOE value for Vol 3.
8. If the MOE result for Vol 3 is greater than the desired LOS threshold, replace Vol 2 with Vol 3.
9. If the LOS result for Vol 3 is lower than the desired LOS threshold, replace Vol 1 with Vol 3.
10. Is the range between Vol 1 and Vol 2 acceptable? If yes, stop and use the average of Vol 1 and Vol 2. If not, repeat Steps 6 through 9.
11. If an hourly volume table is being generated, round down the result of Step 10 to a multiple of at least 10. If a daily volume table is being generated, divide the result of Step 10 by the selected *K*- and *D*-factors and round the result down to a multiple of at least 100.

This reference can be found in the Technical Reference Library in Volume 4.

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