CHAPTER 6
HCM AND ALTERNATIVE ANALYSIS TOOLS

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1. INTRODUCTION

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5. Quality and Level-of-Service Concepts
6. **HCM and Alternative Analysis Tools**
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OVERVIEW

The analysis tools provided by the *Highway Capacity Manual* (HCM) are part of a continuum of tools providing different levels of data needs, sensitivity to input factors, geographic and temporal scope, and detail of outputs. The HCM's tools can be categorized into three broad areas:

- *Operations-level tools.* These are the primary methodologies presented in the HCM's Volume 2 and 3 chapters. They are sensitive to a variety of input factors and have a correspondingly high level of data needs that must be supplied by the analyst on the basis of field or forecast data (or a combination). HCM methods are *deterministic* (i.e., each model run produces the same results, given the same inputs), *macroscopic* (i.e., evaluate the traffic stream as a whole rather than individual vehicles), and generally work with 15-min analysis periods as the smallest unit of time.
- *Application of defaults to operations-level tools.* In many cases, supplying a field-measured or forecast value for every HCM model input may be impractical or unnecessary. Default values can be judiciously substituted for unknown input values when HCM operations methods are applied. The use of local default values is preferred—and a method for developing them is suggested in Appendix A of this chapter—but the HCM also suggests default values when local values are not available.
- *Planning-level tools.* These include (*a*) the application of operations methods with all inputs defaulted that are allowed to be defaulted, (*b*) service volume tables that provide maximum daily or hourly volumes for a particular level of service (LOS) given a set of assumed conditions, and (*c*) other tools that approximate an HCM operations method but require fewer inputs and fewer calculation steps. These tools are typically applied as screening tools; as means for obtaining quick, approximate answers; and as easy-to-use methods for providing inputs to other analysis tools.

One exception to the statement that HCM methods are deterministic is the travel time reliability method, which uses a random number seed to generate scenarios. However, given the same seed, the model will produce the same travel time distribution.

Alternative tools are defined as all analysis procedures outside the HCM that may be used to compute measures of transportation system performance for analysis and decision support. The HCM and alternative tools may be used during different stages of a planning or project development process, depending on the analysis needs (e.g., available data, desired level of detail) at a given time.

Alternative tools span the range from very simple (e.g., single equations estimating a single performance measure) to highly complex (e.g., travel demand models covering an entire region's transportation system). Analysts might consider alternative tools for a variety of reasons, including the following, among others: conditions outside the range covered by an HCM methodology, analyses requiring performance measures not produced by the HCM, and analyses in which the quantity of data required to calculate a performance measure (e.g., areawide multimodal networks) makes HCM methods impractical.

CHAPTER ORGANIZATION

Section 2 describes the three main types of analysis tools provided by the HCM: (*a*) generalized service volume tables, (*b*) application of HCM operations methods with default values, and (*c*) application of HCM operations methods with measured or forecast values. Typical applications for each of these types of tools are described.

Section 3 introduces the range of alternative tools, describes traffic modeling terminology and concepts, examines the conceptual differences between the HCM's analytical modeling and simulation modeling, and presents situations in which alternative tools might supplement HCM procedures. The section provides modeling frameworks for applying alternative tools to different transportation system elements and compares the principal performance measures available from the HCM and from alternative tools. Finally, it provides guidance on the selection of analytical tools for a given situation, along with general guidance on using simulation-based traffic analysis tools for capacity and performance analysis.

Two appendices to the chapter will be of particular interest to analysts conducting planning and preliminary engineering analyses. Appendix A provides guidance on developing local default values, and Appendix B describes how to develop local generalized service volume tables.

RELATED HCM CONTENT

Other HCM content related to this chapter is the following:

- Chapter 7, Interpreting HCM and Alternative Tool Results, where Section 3 includes guidance on defining, measuring, and comparing key outputs of alternative tools when such outputs are intended to be used with or compared with those of the HCM;
- Chapter 36, Concepts: Supplemental, where Section 5 provides guidance on using vehicle trajectory analysis as the "lowest common denominator" for comparing performance measures from different analysis tools;
- The Scope subsections within the Methodology sections of all Volume 2 and 3 chapters, which provide specific guidance about when alternative tools might be considered for analyzing a particular system element;
- The Use of Alternative Tools subsections within the Applications sections of all Volume 2 and 3 chapters, which provide specific guidance on applying alternative tools to the analysis of a system element;
- Case Study 4, Alternate Route 7, in the *HCM Applications Guide* in Volume 4, which provides a high-level example of applying a simulation tool to a freeway facility analysis;
- Case Study 6, I-465 Corridor, Indianapolis, in the *HCM Applications Guide* in Volume 4, which demonstrates how a network simulation model can be used to augment studies conducted with HCM methodologies; and
- The *Planning and Preliminary Engineering Applications Guide to the HCM* in Volume 4, which provides guidance and case study examples of using the HCM in a variety of planning applications.

2. HCM-BASED TOOLS

The HCM provides three main types of tools for analyzing roadway operations: (*a*) generalized service volume tables, (*b*) methods relying on the extensive use of default values, and (*c*) operations-level analysis where all or nearly all inputs come from measured or forecast values. Different HCM tools may be used at different points in the same analysis or at different times as a project progresses from planning to preliminary engineering to design. HCM tools may also be combined with non-HCM (*alternative*) tools in a similar manner. This section describes the potential use of HCM-based tools; the next section does the same for alternative 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 when evaluation of every segment or node within a study area is not feasible. Examples are city, county, or statewide planning studies in which the size of the study area makes a capacity or LOS analysis for every system element infeasible. For these types of applications, the focus of the effort is on highlighting 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.

A service volume represents the maximum number of vehicles that the system element can carry at a specified LOS, given assumed inputs.

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 service measure 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 roadway 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. These tables should not be used as a substitute for other tools in making a final determination of the operational adequacy of a particular roadway. Application of local service volume tables based on local default values, as described in Appendices A and B, helps make the results less approximate than would application of the HCM's tables, which are based on national default values.

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. With these inputs, a user can read the service volume for a given LOS directly from the table and compare

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

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 many planning, preliminary engineering, and design applications of the HCM, an analyst may take an HCM methodology directly from one or more of the chapters in Volumes 2 and 3 but use 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.

Although the HCM provides default values for its methodologies, the analyst should be mindful that they represent typical national values and that typical conditions within a state, region, or community may be different. When default values are applied frequently in analyses, the use of local default values can help 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 core HCM methodology directly and use no, or minimal, default values.

In an operations-level analysis, an analyst applies a core 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.

The chapters in Volumes 2 and 3 identify methodological limitations that may cause analysts to consider alternative tools.

An operations-level analysis is applicable to any situation covered by a core HCM methodology. Analysts should refer to the Limitations of the Methodology subsections of the HCM Volume 2 or 3 chapter being applied to ensure that the HCM methodology is appropriate for the specifics of the situation being studied. The Alternative Tool Considerations subsections that are also provided in Volume 2 and 3 chapters describe specific cases when alternative tools might be considered.

3. ALTERNATIVE TOOLS

OVERVIEW

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

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

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 the literature describing alternative tools and their applications is abundant. 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 or to use HCM performance measures as inputs, 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.

The Traffic Analysis Toolbox *is available at http://ops.fhwa.dot.gov/trafficanalysistools/.*

Clearly, readers should use the material presented here in conjunction with other documents that address analysis, modeling, and simulation of transportation systems. In particular, a considerable volume of authoritative information on this subject is available in the Federal Highway Administration's *Traffic Analysis Toolbox*, which was described in Section 6 of Chapter 1, HCM User's Guide.

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. Volume I of the *Traffic Analysis Toolbox* (*1*) 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, chapters in HCM Volumes 2 and 3 present guidance on the treatment of bicycles, pedestrians, and buses. The best source of guidance on the use of alternative tools for other modes is the detailed documentation and user's guide provided with tools that offer these features.

The material in this section also focuses on alternative tools that address limitations of HCM operational methods. Planning-level tools that calculate performance measures that the HCM also produces (typically with fewer calculation steps and less sensitivity to factors that influence performance) are discussed in the *Planning and Preliminary Engineering Applications Guide to the HCM*, located in online Volume 4.

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 (2), "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 (2), "a hypothetical description of a complex entity or process." Here is the root of the inconsistent usage. On the basis of 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"(3). For HCM purposes, *model* is used in this sense but is more precisely defined as "a procedure that uses one or more algorithms to produce a set of numerical outputs describing the operation of a transportation 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 is generally 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 shortened in the HCM to *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 entry of input data and the interpretation of 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 situation being analyzed. The following terms are defined in Volume III of the *Traffic Analysis Toolbox* (4):

- *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 result in the best reproduction of field-measured local traffic conditions by the model.
- *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

Different types of tools have different objectives and provide different types of output.

Volume I of the *Traffic Analysis Toolbox* identifies the following categories of traffic analysis models (*1*):

- *Sketch-planning tools* produce general order-of-magnitude estimates of travel demand and transportation system performance under various transportation system alternatives.
- *Travel demand models* forecast long-term travel demand on the basis of current conditions and projections of socioeconomic characteristics and changes in transportation system design.
- *HCM-based analytical deterministic tools* 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* utilize 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 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., *5–8*). 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

The terms *static flow* and *time-varying flow* relate to the temporal characteristics of the traffic flows in the simulation model. 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 static flow models, users provide a single set of flow rates. The model may vary headways, but the demand is fixed and does not change throughout the duration of the analysis.

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 demand 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 demand can vary over time. Most models change flows once an hour, but some allow more frequent changes.

In the time-varying case, flow rates can change with time. More than one set of flow rates must be specified so that the demand 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 through advance lane blockage signs would not necessarily be a descriptive model.

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.

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.

DTA models are a type of descriptive model using 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.

Traffic assignment models are a special case, because they use 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 demand characteristics are constant or time-varying. Most simulation tools have some form of dynamic traffic assignment (DTA). Because of its computer resource demands, DTA is often implemented at the mesoscopic level. DTA models are often combined with microsimulation models to create hybrid models.

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 travel time reliability, toll prices, number of stops, and 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 ANALYTICAL 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. One important difference is that HCM procedures work with fixed demand, typically the output of assignment (planning or dynamic). Most of the other differences may be described in terms of how analytical and simulation tools deal with various traffic flow phenomena. Examples of the significant differences are identified in general terms in Exhibit 6-1.

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	

APPROPRIATE USE OF ALTERNATIVE TOOLS

Situations in which alternative tools might supplement HCM procedures.

Use of 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 or range of the analysis has elements that are beyond the scope of the HCM procedures. Each Volume 2 and 3 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 vehicle delays produced by 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, that are beyond the scope of the HCM.
- The system under study involves a group of different facilities or travel modes with mutual interactions involving several HCM chapters. 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.
- Active traffic and demand management (ATDM) or other advanced strategies are being evaluated.

Compatibility of performance measures with the HCM procedures is essential for the use of alternative tools to supplement or replace the HCM procedures.

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

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

- Is use of the tool acceptable to the agency responsible for approving decisions that result from it?
- Are the necessary resources, time, and expertise available to apply the tool?
- Does the application rely on a traceable and reproducible methodology?
- Have assumptions used to apply the tool been sufficiently documented?
- Are sufficient and appropriate data available to capitalize on or leverage the strength of the tool?
- Is sufficient time available for calibration to promote a robust reliance on the model output?

- Are the 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 not 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.

Exhibit 6-2
Typical Applications for Alternative Traffic Analysis Tools

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

For corridor and areawide analysis, aggregation of the results from Volume 2 and Volume 3 procedures requires 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 ATDM, congestion pricing, and freight corridors.

Alternative tool applications may be appropriate for evaluating ATDM measures that require finer temporal sensitivity to dynamic changes in the system than can be provided by the typical 15-min HCM analysis period. This may occur in evaluating traffic-responsive signal timing, traffic adaptive control, dynamic ramp metering, dynamic congestion pricing, or strategies affecting the prevalence or duration of incidents with less than 10-min durations. There may also be scenarios and configurations that the HCM cannot address, such as application of ATDM measures in complex merging and diverging situations on freeways.

More information on ATDM measures and their evaluation can be found in Chapter 37, ATDM: Supplemental.

The ATDM analysis framework can work with a wide variety of operations analysis tools ranging from microscopic simulation models to mesoscopic simulation models, traffic control optimization models, and HCM-based macroscopic analysis models. The key is to select an analysis tool with the appropriate geographic scale and sensitivities to ATDM improvements that meets the agency's objectives for the analysis and at the same time has data and calibration requirements within the agency's resource constraints.

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.

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

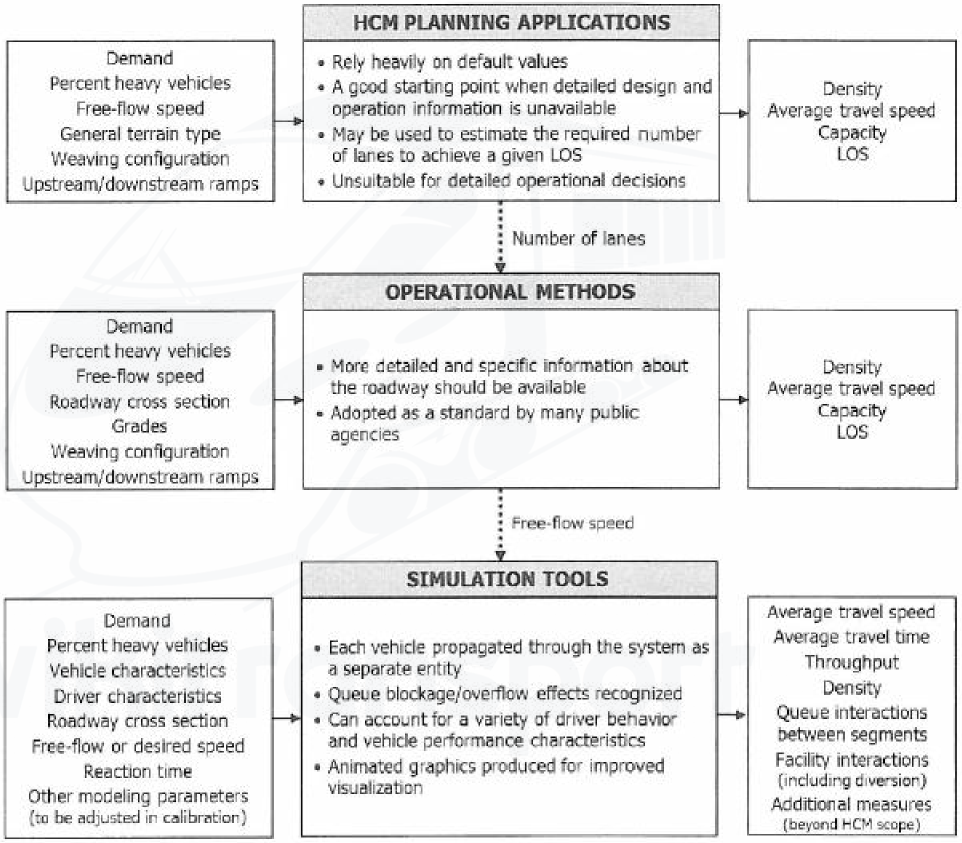
The principal classes of tools are

- HCM planning applications;
- Operational tools, including the HCM methodology described in Volume 2 and a variety of other macroscopic analysis tools; and
- Simulation tools that utilize microscopic, mesoscopic, and hybrid models.

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

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

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



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

- *HCM quick-estimation method for signalized intersections,* which is based primarily on critical movement analysis and default values;
- *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.

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.

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

Microsimulation tools are used in urban street analysis, mainly to deal with complex intersection phenomena beyond the capabilities 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 capabilities of the HCM.

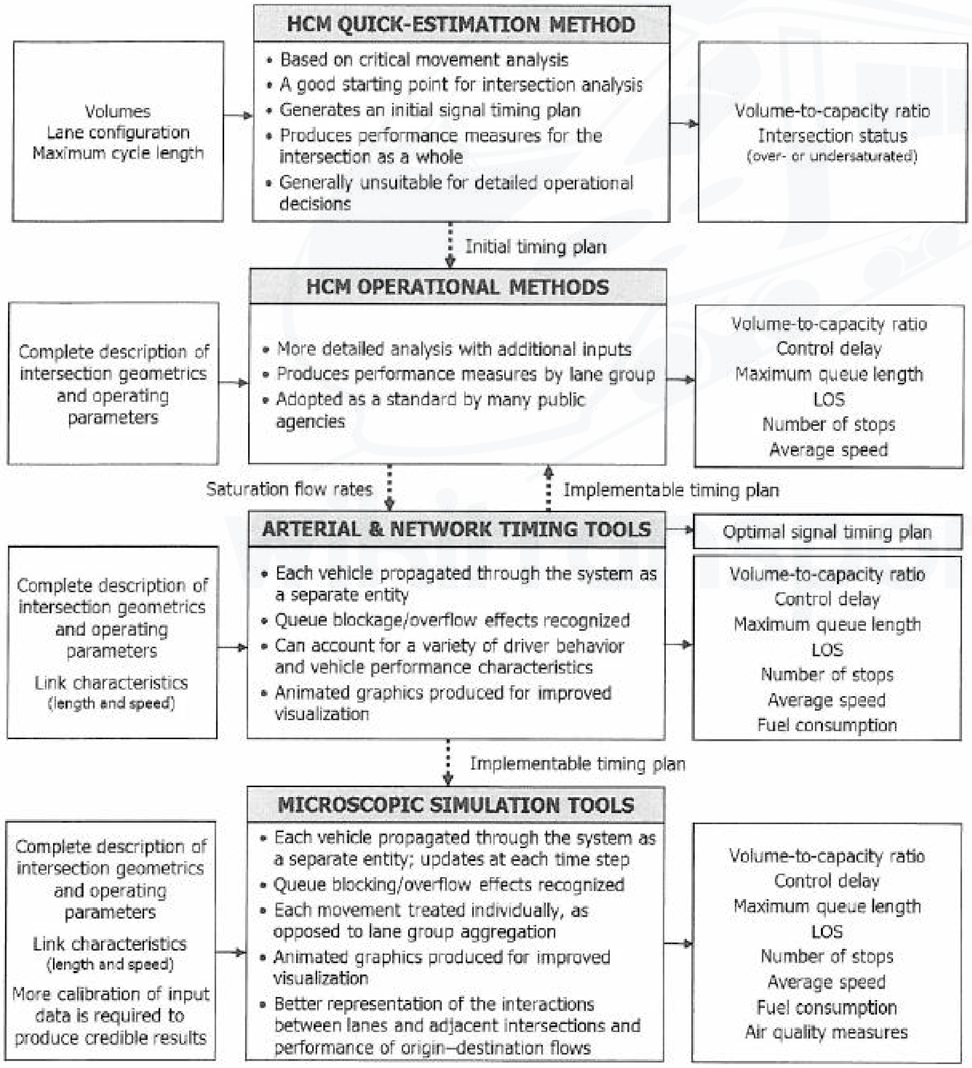


Exhibit 6-4
Urban Street Modeling Framework for the HCM and Alternative Tools

Source: *Signalized Intersections: Informational Guide* (*9*).

Two-Lane and Multilane Highways

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

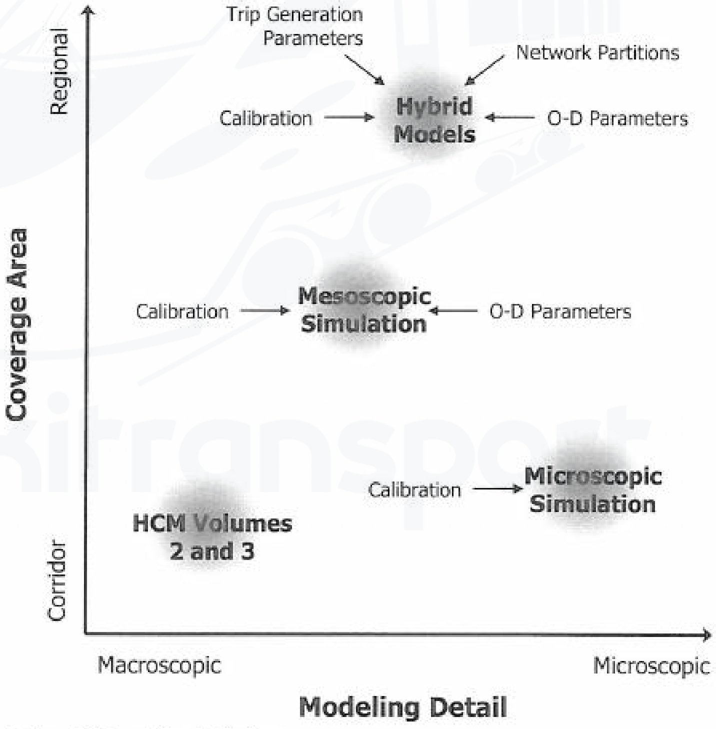
At this point, application of alternative tools for the analysis of either type of highway is minimal. The HCM is the only macroscopic deterministic tool in common use, although some states such as Florida have developed their own analysis tools that implement derivatives of HCM procedures (*10*). At 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.

Corridor and Areawide Analysis

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

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.

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



Note: O-D = origin–destination.

An excellent reference for corridor and areawide simulation (*11*) is available from a U.S. Department of Transportation research initiative on integrated corridor modeling. It provides detailed guidance on conducting 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 (*11*), 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 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 large geographical area without loss of detail at critical intersections and interchanges.

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, use of a tool that quantifies the effects of queuing as well as stops and delay is necessary. 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.

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.

If an alternative tool is used to analyze highway capacity and quality of service, 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.

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

Uninterrupted-Flow Chapters (Volume 2)

HCM Chapter and Topic	Speed	Delay	Through-put	Reli-ability	Density	% Time-Spent-Following	Passing	Environ-mental	Demand/ Capacity
10. Freeway Facilities	H, A	H, A	H, A	X	H, A	X	X	A	X
11. Freeway Reliability	H, A	X	X	H, A	X	X	X	X	X
12. Basic Segments	H, A	A	H, A	X	H, A	X	X	A	H
13. Weaving	H, A	A	H, A	X	H, A	X	X	A	H
14. Merges/Diverges	H, A	A	H, A	X	H, A	X	X	A	H
15. Two-Lane Highways	H, A	H	H	A	A	H	H, A	A	H

Interrupted-Flow Chapters (Volume 3)

HCM Chapter and Topic	Delay	Stops	Through-put	Reli-ability	Queue Length	Cycle Failure	Environ-mental	Speed	Demand/ Capacity
16. Urban St. Facilities	H, A	H, A	H, A	X	H, A	A	A	H, A	H
17. Urban St. Reliability	X	X	X	H, A	X	X	X	H, A	X
18. Urban St. Segments	H, A	H, A	H, A	X	H, A	A	A	H, A	H
19. Signals	H, A	A	H, A	X	H, A	A	A	X	H
20. TWSC	H, A	A	H, A	X	H, A	X	A	A	H
21. AWSC	H, A	A	H, A	X	H, A	X	A	A	H
22. Roundabouts	H, A	A	H, A	X	H, A	X	A	A	H
23. Ramp Terminals	H, A	A	H, A	X	H, A	A	A	X	H
24. Pedestrian/Bicycle	X	X	X	X	X	X	X	H	H[a]

Source: Adapted from Dowling (*12*).

Notes: [a] Pedestrian mode only.

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.

St. = Street, TWSC = Two-way STOP-control, AWSC = All-way STOP-control.

TRAFFIC ANALYSIS TOOL SELECTION CRITERIA

The Traffic Analysis Toolbox *is available at http://ops.fhwa.dot.gov/trafficanalysistools/.*

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* [e.g., in Volume II (*13*)] should be studied thoroughly before a major traffic analysis project is undertaken.

Determining Project Scope

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

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

Examples of ITS features not covered by the HCM include traffic-responsive signal timing, traffic-adaptive control, dynamic ramp metering, dynamic congestion pricing, and strategies affecting the prevalence or duration of incidents with less than 10-min durations.

Assessing HCM Methodologies

Another essential step in the analysis tool selection process is to assess the capability of the existing HCM methodologies and to determine whether they 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 an alternative tool is determined to be needed or advisable, the most appropriate tool must be selected.

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

Selecting a Traffic Analysis Tool

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 those of the HCM procedures, which are also deterministic. Deterministic tools also tend to work at the same macroscopic level as the HCM. Alternative deterministic tools fall mainly into the following categories:

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

- Tools for signal-timing plan design and optimization,
- Proprietary deterministic models offering 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. The following steps describe a suggested simulation model development process (*14*):

- 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 as follows:

- 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 left-turn capacity due to opposing traffic in a signalized intersection, and
- Route selection behavior.

These points may be used as a basis for discussion with the model developer by those wishing to gain a better understanding of the development or operation of candidate simulation tools.

Model Capabilities

Key model features to consider.

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.

- *Network size.* Most tools limit the network size 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, bicycles, and pedestrians 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 use dynamic assignment logic to distribute vehicles over the available paths in a realistic way. Simulation models offer varying degrees of DTA features and may allow 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 communications.
- *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 ascertained. 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 occur among tools. Most simulation models use a link-based scheme in which links represent roadway segments that are connected in some manner. Required link data include endpoint coordinates, link length, number of lanes per link, lane additions, lane drops, lane channelization at intersections, turning pockets, grade, and horizontal curvature. 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, origin–destination (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 result in the best reproduction of field-measured local traffic operations conditions by the model. Vehicle and driver characteristics, which may be site-specific and require calibration, are the key parameters for microscopic traffic simulation models. Of course, the type of simulation model that is being used for a particular application determines the type of parameters that need to be calibrated. For example, in macroscopic traffic simulation models, the behavior of the drivers and the performance of the network are represented with more aggregate models, such as the speed–density relationship and the link input and output capacities. In that case, the parameters that need to be calibrated differ from those outlined above, but the process is fundamentally the same. For example, a specific application may require calibration of the parameters of the speed–density relationship of groups of links and the capacities of the network links.

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 for better reflection of local conditions should be identified. Most simulation tools allow the analyst to override the default driver behavior data and vehicle data to improve the match with 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 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, lane-changing and car-following behavior, 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 and deceleration, fuel consumption rate, and emissions 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 for leveraging previously collected data, with the caveat that the data should continue to be representative of current conditions. 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 understood 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 at its first release, and all require continuous maintenance as well as periodic enhancements.

Verification and Validation

Assessment of how extensively a given model has been verified is important. In many cases, but not all, simulation models are also validated as part of the formulation and development process. Certainly, validated models 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. Evidence of validation in professional journals and periodicals is useful.

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 the Volume 4 supplemental chapters, the *HCM Applications Guide,* and the *Traffic Analysis Toolbox*, as mentioned previously.

The Traffic Analysis Toolbox *is available at http://ops.fhwa.dot.gov/trafficanalysistools/.*

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 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.

The initial model run should (a) represent the initial state of the traffic environment before statistics are collected, (b) cover the entire analysis period, and (c) specify the dynamic input conditions describing the traffic environment (for models capable of handling time-varying input).

Three critical issues must be addressed when an initial simulation model run is conducted for the baseline case. First, the model should represent the initial state of the traffic environment before any statistics are 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.

In addition, 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 calibrating and validating models may be found in the *Traffic Analysis Toolbox*.

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. Routes and route flows may also be implicitly represented in a model by splitting rates, which are turning proportions at nodes by destination. The use of explicit routes to move vehicles through the simulation obviates the use of turning proportions at nodes. 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 it 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 generate 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. Several references on DTA are available (e.g., *15, 16*).

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 the *Traffic Analysis Toolbox* for details on the design and analysis of stochastic simulation models.

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.

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APPENDIX A: DEVELOPING LOCAL DEFAULT VALUES

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

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

Local default values can be developed by conducting measurements of "raw data" in the geographic area where the values are to be applied. Default values are usually 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 and the number of travel lanes. In developing generalized service volume tables for daily service volumes, the *K*- and *D*-factors selected must be consistent with measured local values.

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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APPENDIX B: DEVELOPING LOCAL SERVICE VOLUME TABLES

INTRODUCTION

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.

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.

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

When the service volume table is applied, the unlikelihood of a match between all of the input parameters for the various roadway segments being evaluated and the default inputs needs to be recognized. Accordingly, conclusions drawn from the use of service volume tables should be considered and presented as rough approximations.

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.

TABLE CONSTRUCTION PROCESS

Service volume tables are generated by applying software to back-solve for the maximum volume associated with a particular LOS, given the analyst's selected set of default values. 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.
2. Identify the threshold value associated with the system element's service measure 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 service measure 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 at least 100 for daily volume tables. If the table is being created

by manually applying software, the analyst can observe how closely the service measure result is converging toward the LOS threshold 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.

5. Identify the threshold value for the next LOS and repeat Steps 4 and 5 until threshold volumes have been found or unachievability has been determined for each LOS.
6. If a daily volume table is being created, divide the 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 value used for one of the input parameters (e.g., number of lanes) and repeat Steps 2 through 6 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. Label the first achievable test volume *Vol 1*.
2. Select a second iteration volume (*Vol 2*) by doubling Vol 1.
3. Compute the service measure value for Vol 2.
4. If the resulting service measure 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 service measure result is greater than the desired LOS threshold.
5. Use the bisection method described in Steps 6 through 10 (*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 and label it *Vol 3*.
7. Compute the service measure value for Vol 3.
8. If the service measure 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 the result of Step 10 down 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.

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