CHAPTER 3

APPLICATIONS

CONTENTS

EXHIBITS

I. INTRODUCTION

This chapter provides an overview of the *Highway Capacity Manual* (HCM) analyses and describes how to apply them to a range of facilities. The scope of the manual and the framework for its application is followed by a description of the levels at which an analyst can apply the methods. The chapter concludes with an outline of how to use HCM analyses as input to other models.

II. FRAMEWORK FOR APPLICATION OF THE HCM

ANALYSIS OF INDIVIDUAL ELEMENTS

The purpose of the HCM is to produce estimates of performance measures for individual elements or facilities of a transport system, as well as to combine those elements to expand the view of the system. Exhibit 3-1 tabulates the various system elements for which the HCM provides analysis methodologies. The chapters shown appear in Part III of the HCM, which deals with methodologies. Other chapters provide background on related concepts.

SYSTEM ANALYSIS

Concept of system analysis

Measures of effectiveness (MOEs)—performance measures that can be estimated quantitatively—are produced for individual system elements (and in some cases, subelements) by the methods in each chapter of Part III. These measures allow combination of the elements to produce an expanded view of a facility. For example, an analysis of a signalized intersection might consider individual movements, or groups of movements, on each approach. The results then can be successively combined to determine MOEs for each approach, each street, and the intersection as a whole. Similarly, the outputs from models for analyzing each element of a freeway facility can be combined to provide a result for a section of the freeway, including ramp junctions, weaving segments, and basic segments.

It is also possible to extend this procedure by combining the results of analyses of individual facilities to represent successively larger portions of a whole system, as addressed in Part IV of this manual. A system includes the corridors, with one or more types of facility or mode, as well as the areas representing all or part of the transportation network under study.

Exhibit 3-2 depicts a system analysis—combining the analyses of individual elements to produce an aggregate view of a facility, a corridor, or an area. The diagram provides an example that applies only to urban systems. Each box represents a method of analysis covered in this manual, indicating the element, or combination of elements, included. The box also indicates the chapter in which the applicable methodology is presented (Parts III and IV); however, there are also materials in other parts of the manual that might apply, especially in Part II. Finally, each box indicates the appropriate performance measures that can be derived from the chapter and that are applicable to a system analysis.

In general, speed and delay are the variables that derive from an analysis of individual elements and that can be used to calculate measures for system analysis. Usually this is done by converting the estimates of speed and delay into travel times and then aggregating the travel times across individual elements. In some cases, however, speed and delay can be averaged and used as performance measures even at aggregate levels.

EXHIBIT 3-1. FACILITIES AND ROAD USER TYPES INCLUDED IN HCM ANALYSES

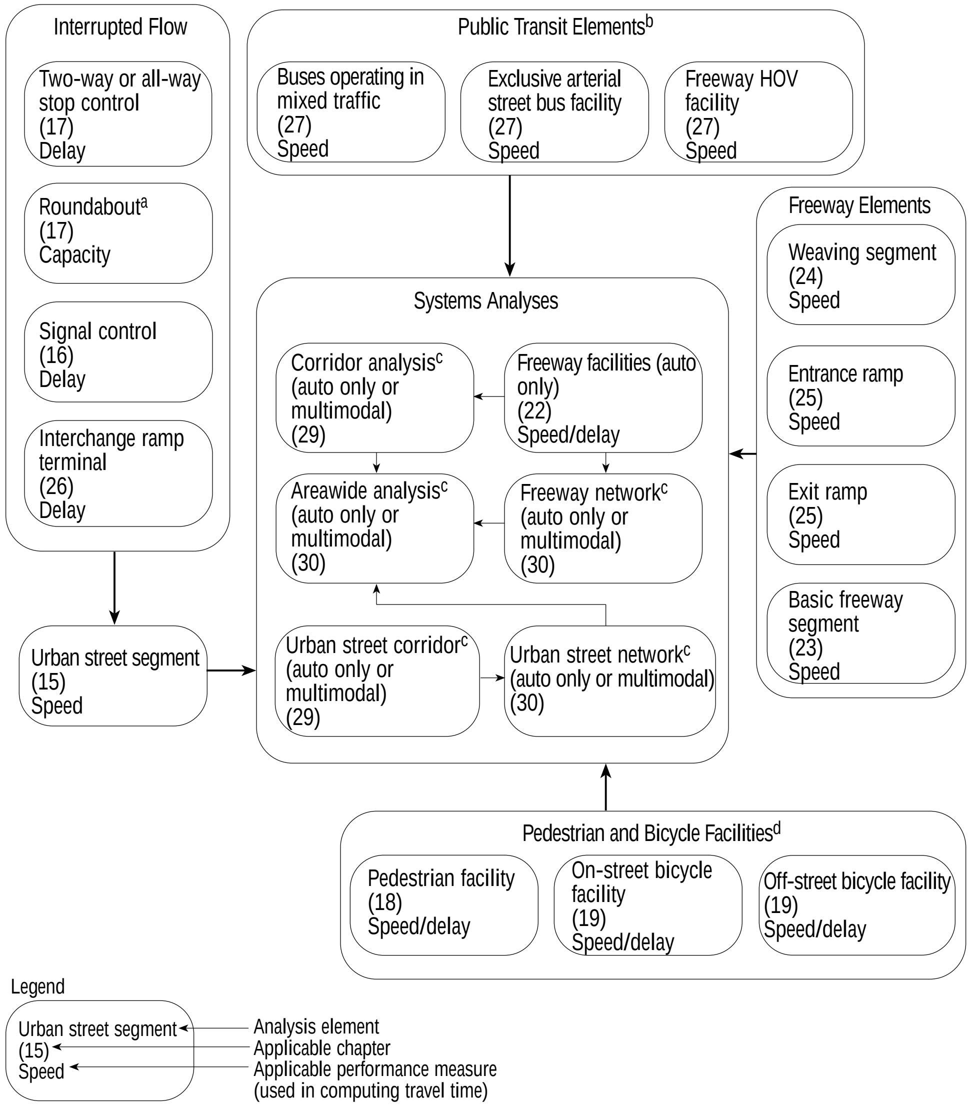
Element	Chapter[a]	Service Measure[b]	Reference Points on Exhibit 3-3	Performance Measure Used to Calculate Travel Time Systems Analysis
Vehicular				
Interrupted Flow				
Urban street	15	speed	L, P	speed
Signalized intersection	16	delay	H, O	delay
Two-way stop intersection	17	delay	I, J, M, N	delay
All-way stop intersection	17	delay	I, J, M, N	delay
Roundabout	17	[c]	K	delay
Interchange ramp terminal	26	delay	Q, R, S	delay
Uninterrupted Flow				
Two-lane highway	20	speed, percent time-spent-following		speed
Multilane highway	21	density		speed
Freeway				
Basic segment	23	density	B, X, Z	speed
Ramp merge	25	density	A, E, V, Y	speed
Ramp diverge	25	density	C, D, G, U, W	speed
Weaving	24	speed	F	speed
Other Road Users				
Transit	27	[d]	[e]	speed
Pedestrian	18	space, delay	[f]	speed, delay
Bicycle	19	event, delay	[g]	speed, delay

Notes:
a. Only Part III chapters are listed. When performing planning level analyses, the analyst should refer to Part II, for further guidelines and for selection of default values.
b. The service measure for a given facility type is the primary performance measure and determines the level of service.
c. HCM does not include a method for estimating performance measures for roundabouts. Non-HCM models that produce a delay estimate must be employed.
d. Several measures capture the multidimensional nature of transit performance when defining LOS; see Chapter 27.
e. Transit facilities, such as buses in mixed traffic, buses on exclusive lanes, buses in high-occupancy vehicle (HOV) lanes, and rail vehicles, can be analyzed separately as a transit system, or combined for a multimodal analysis.
f. Pedestrian facilities, such as sidewalks and walkways, form a system and can be analyzed separately. Pedestrian delay at signalized intersections can be predicted or measured, and a multimodal analysis can include estimates of person delay, person travel time, and speed.
g. Bicycle facilities—such as bicycles in traffic, bicycle lanes, and separate bicycle paths—form a system and can be analyzed separately. Speed of bicycles in traffic and on bicycle lanes can be predicted or measured, and a multimodal analysis can include estimates of person delay, person travel time, and speed.

The boxes referring to the basic analysis of individual elements are placed on the periphery of the diagram. The results of these analyses are aggregated at successively higher levels, until the objective is achieved. For example, Chapter 15 shows the analyst how to combine the results of delay estimates for unsignalized and signalized intersections with speed and travel time on the links between these points, to determine an average speed for an urban street segment. The analysis of a street segment can include pedestrian, bicycle, and transit modes. These can be combined with parallel segments to arrive at a result for a corridor analysis. A corridor analysis (Chapter 29) can involve combining results from analyses of uninterrupted-flow facilities, as well as transit, pedestrian, and bicycle facilities. Areawide analysis is the highest level of study possible (Chapter 30). The systems analyses that can be performed using this manual are shown in the central box of Exhibit 3-2.

An example of how to aggregate individual elements of urban systems to perform a system analysis

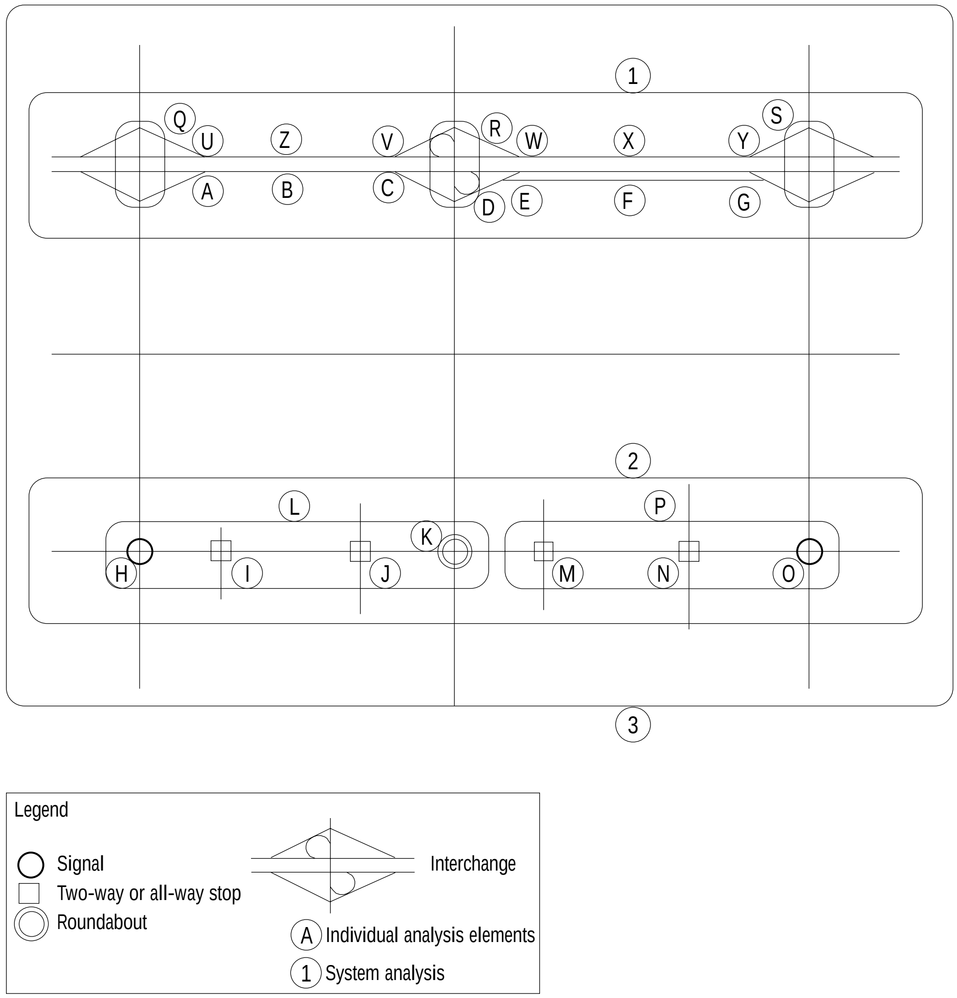
EXHIBIT 3-2. EXAMPLE OF HCM APPLICATION TO ANALYSIS OF URBAN SYSTEMS



Notes:
a. Current HCM methods do not provide models for estimating delay at roundabouts. The user may employ other models to complete the analysis.
b. Public transit elements can be analyzed as a separate system, using a variety of performance measures provided in Chapter 27, or as part of a larger system using travel speed as the common performance measure.
c. The chapters on corridor and areawide analysis do not specify a specific MOE for defining LOS. Instead, performance measures are defined for five dimensions: quantity of service produced by the system; intensity of congestion; extent of congestion; variability of the measures; and accessibility.
d. Pedestrian and bicycle elements can be analyzed as a separate system, using the performance measures provided in Chapters 18 and 19, or as part of a larger system using travel speed as the common performance measure.

Exhibit 3-3 is a schematic of a typical urban network. The interrupted-flow elements along an arterial are included when determining LOS for urban street segments; for example, analysis of urban street Segment L will include the results from analysis of Intersections H, I, J, and K. These may be further combined for an arterial corridor analysis (designated as 2 in the exhibit). Similarly, the freeway facility (designated by 1) is a combination of the individual elements within it. A freeway corridor analysis combines the freeway with one or more parallel arterials. An area analysis (designated by 3) further accumulates the values for the appropriate performance measures from preceding stages. System analyses can consider only one mode or user type or combine several modes or user types.

EXHIBIT 3-3. COMPONENTS OF HCM ANALYSIS OF URBAN SYSTEMS



Looking at Exhibit 3-1, the right portion identifies the performance measures used to compute travel time and to analyze the constituent elements of the system in Exhibit 3-3. Exhibit 3-2 lists the chapters in HCM Parts III and IV that include guidelines and methods for combining performance measures.

RANGE OF OPERATIONAL CONDITIONS COVERED

The HCM can be used to analyze a wide range of operational conditions. The methodologies can determine the performance and LOS for undersaturated conditions and, in some cases, for oversaturated conditions. There are two primary ways of dealing with oversaturation: one is to conduct analyses over successive 15-min periods of congestion; the other is to account for queue interference when downstream conditions cause queue buildup to affect upstream elements.

The analyst can work with individual 15-min periods, or hourly periods for which peak-hour factors are established. This flexibility expedites analyses over several hours of the day, allowing the analyst to consider both peak and off-peak conditions, as well as 24-h totals.

III. ANALYSIS OBJECTIVES

HCM analyses produce information for decision making. Users of the manual generally are trying to achieve one of three objectives: identify problems, select countermeasures (a priori evaluation), or evaluate previous actions (post hoc).

Why an analyst might want to use the HCM

Problems usually are identified when performance measures for a network or a facility—or a portion of one—do not meet established standards. For example, when the service on a facility falls below LOS D, the resultant queuing might interfere with operation upstream. Although the HCM is well suited for predicting performance measures, an analyst studying current conditions should make direct field measurements of the performance attributes. These direct measurements then can be applied in the same manner as predicted values to determine LOS. The HCM, however, is particularly useful when a current situation is being studied in the context of future conditions, or when an entirely new element of the system is being considered for implementation.

Once a problem is identified in measurable terms, the analyst can establish the likely underlying causes and countermeasures, with the goal of making operational improvements. For example, an analyst might identify a problem with pedestrian queuing at an intersection. Review of the physical conditions leads to several alternative countermeasures, including removal of sidewalk furniture or expanding the sidewalk area. These countermeasures can be tested for any attribute of the facility that is reflected in the HCM models. For example, an analyst can compare alternatives for intersection control, certain geometric design improvements, or improvements in traffic signal timing.

Historically, there is little evidence that the HCM has been used to evaluate the effectiveness of actions once they have been implemented, but it can be useful for this. However, it is imperative to make direct field measurements of the appropriate performance measures while working within the general framework of the HCM process.

LEVELS OF ANALYSIS

Operational, design, and planning analyses

The levels of analyses commonly performed by users of the HCM can be grouped into three categories: operational, design, and planning.

Operational analyses are applications of the HCM generally oriented toward current or anticipated conditions. They aim at providing information for decisions on whether there is a need for minor, typically low-cost, improvements that can be implemented quickly. Occasionally, an analysis is made to determine if a more extensive planning study is needed. Sometimes the focus is on a network, or a part of one, that is approaching oversaturation or an undesirable LOS: When, in the near term, is the facility likely to fail? Answering this question requires an estimate of the service flow rate allowable under a specified LOS.

HCM analyses also help in making decisions about operating conditions. Typical alternatives often involve the following: lane-use configurations, application of traffic control devices, signal timing and phasing, spacing and location of bus stops, frequency of bus service, and addition of an HOV lane or a bicycle lane. The analysis produces operational measures for a comparison of the alternatives.

Because of the immediate, short-term focus of operational analyses, it is possible to provide detailed inputs to the models. Many of the inputs may be based on field measurements of traffic, physical features, and control devices. Generally, the use of default values is inappropriate at this level of analysis.

Design analyses apply the HCM primarily to establish the detailed physical features that will allow a new or modified facility to operate at a desired LOS. Design projects usually are targeted for mid- to long-term implementation. Not all the physical features that a designer must determine are reflected in the HCM models. Typically, analysts using the HCM are seeking to determine such elements as the basic number of lanes required and the need for auxiliary or turning lanes. However, an analyst also can use the HCM to establish values for elements such as lane width, steepness of grade, the length of added lanes, the size of pedestrian queuing areas, sidewalk and walkway widths, and the dimensions of bus turnouts.

The data required for design analyses are fairly detailed and are based substantially on proposed design attributes. However, the intermediate- to long-term focus of the work will require use of some default values. This simplification is justified in part by the limits on the accuracy and precision of the traffic predictions with which the analyst will be working.

Planning analyses are applications of the HCM generally directed toward strategic issues; the time frame usually is long-term. Typical studies address the possible configuration of a highway system (or portion of one); a set of bus routes; the expected effectiveness of a new rail service; or the likely impact of a proposed development. An analyst often must estimate the future times at which the operation of the current and committed systems will fall below the desired LOS. Planning studies also can assess proposed systemic policies, such as lane-use control for heavy vehicles, application of systemwide freeway ramp metering, and the use of demand-management techniques, such as congestion pricing.

Exhibit 3-4 demonstrates the general relationship between the levels of analysis and their objectives. Each of the methodological chapters (Part III of the HCM) has one basic method adapted to facilitate each of the levels of analysis. Planning analyses generally are simplified by using more default values than analyses of design and operations.

EXHIBIT 3-4. LEVELS AND OBJECTIVES OF TYPICAL HCM ANALYSES

Level of Analysis	Analysis Objective		
	Problem Identification	Countermeasure Selection (A Priori)	Evaluation (Post Hoc)
Operational	Primary	Primary	Primary
Design	Not applicable	Primary	Secondary
Planning	Secondary	Primary	Not applicable

HCM ANALYSES AS PART OF A BROADER PROCESS

Environmental impact analysis

Since its first edition in 1950, the HCM has provided transportation analysts with the analytical tools to estimate traffic operational measures such as speed, density, and delay. It also has provided insights and specific tools for estimating the effects of various traffic, roadway, and other conditions on the capacity of facilities. In the past 10 to 15 years, the calculated values from the HCM increasingly have been used in other transportation work, such as project analysis both in terms of the environment and in terms of user costs and benefits. This practice of using estimated or calculated values from HCM work as the foundation for estimating user costs and benefits in terms of economic value, environmental changes (especially air and noise), and even implications on safety, is particularly pronounced in transportation priority programs and in the justification of projects. A good description of what non-HCM users do with HCM-produced material is found in a handbook, *Environmental and Energy Considerations* (*1*, p. 447):

> *The environmental analyst is required carefully and objectively to examine project data provided by transportation planners and designers, review existing environment laws and regulations which may affect the project, make appropriate calculations of impact, compare impact values against acceptable criteria, and recommend mitigation where needed.*

In a similar manner, the economic analysis of transportation improvements depends heavily on information generated directly through use of the HCM. From an authoritative source of traditional road user benefit and cost analysis, the following excerpt indicates the degree to which such analyses depend on the HCM:

> *Many of the highway user cost factors in this manual are shown as a function of either traffic speed or of the ratio of traffic volume to highway capacity (v/c ratio). The key highway design and traffic characteristics that define capacity and traffic speed can be translated into these parameters through the use of such documents as the* Highway Capacity Manual (*2*, p. 1).

This indicates the strong link between economic analysis and HCM results.

A paper in *Transportation Quarterly* identifies the need for measures of performance that take into account person movement through a system or area (*3*). The paper suggests that by taking both accessibility and mobility into account, an areawide measure of service level can be developed. Also, many environmental analyses (e.g., of ozone formation) and economic analyses (e.g., of vehicle kilometers of travel or system hours of travel) can be conducted only from a systemwide or areawide perspective.

The three performance measures that play key roles in programs related to the Clean Air Act Amendments of 1990 and in related air quality monitoring are vehicle kilometers of travel, vehicle trips, and average travel speeds. These measures also are applicable to assessments of air quality (*1*). This manual provides a measure of average travel speeds for many facility types, but in some cases uses another measure (such as density) to describe LOS. The Intermodal Surface Transportation Efficiency Act regulations of 1991 specify that the movement of people and not just vehicles should be measured in the ongoing monitoring programs. Part IV of this manual addresses person movement in the context of corridor and areawide analyses.

Economic analysis

The economic analysis of highway improvements is an important decision-making tool. A recent analysis of a highway widening project (*4*) referred to the HCM (1985 edition), using average running speed along the highway in question as the important variable in the model. In addition to running speed and delay, the model's major component was the change in number of accidents from before to after the highway improvement. It is noteworthy that some 95 percent of the benefits ascribed to the project came from delay savings and from reductions in vehicle operating costs—both measures calculated with the foundation of HCM speed data.

In summary, almost all economic analyses and all air and noise environmental analyses have relied directly on one or more measures estimated or produced with HCM calculations. Exhibit 3-5 lists the performance measures from this manual that are applicable to environmental or economic analyses.

IV. REFERENCES

1. *Environmental and Energy Considerations*. Transportation Engineering Handbook, Institute of Transportation Engineers, Washington, D.C., 1991.
2. *A Manual of User Benefit Analysis of Highway and Bus Transit Improvements*. American Association of State Highway and Transportation Officials, Washington, D.C., 1977.
3. Ewing, R. Measuring Transportation Performance. *Transportation Quarterly*, Winter, 1995, pp. 91–104.
4. Wildenthal, M. T., J. L. Buffington, and J. L. Memmott. Application of a User Cost Model To Measure During and After Construction Costs and Benefits: Highway Widening Projects. In *Transportation Research Record 1450*, TRB, National Research Council, Washington, D.C., 1995, pp. 38–43.

EXHIBIT 3-5. HCM PERFORMANCE MEASURES FOR ENVIRONMENTAL AND ECONOMIC ANALYSES

	Chapter	Performance Measure (*Service Measure)	Appropriate for Use		
			Air	Noise	Economic
15	Urban Streets	Travel speed*	√	√	√
		Running time	√		√
		Intersection control delay	√		√
16	Signalized Intersections	Control delay*	√		√
		v/c ratio	√		√
17	Unsignalized Intersections	Control delay*	√		√
		Queue length	√	√	√
		v/c ratio	√		√
18	Pedestrians	Space*			
		Pedestrian delay*			
		Speed			√
		v/c ratio			√
19	Bicycles	Hindrance*			
		Events			
		Control delay*			√
		Travel speed*			√
20	Two-Lane Highways	Percent time-spent-following*			
		Speed*	√	√	√
21	Multilane Highways	Density*			
		Speed	√	√	√
		v/c ratio	√		√
22	Freeway Facilities	Density			
		Veh-h delay			√
		Speed	√	√	√
		Travel time			√
23	Basic Freeway Segments	Density*			
		Speed	√	√	√
		v/c ratio	√		√
24	Freeway Weaving	Density*			
		Weaving speed	√	√	√
		Nonweaving speed	√	√	√
25	Ramps and Ramp Junctions	Density*			
		Speed	√	√	√
26	Interchange Ramp Terminals	Control delay*	√		√
27	Transit	Service frequency*	√	√	√
		Hours of service*	√	√	√
		Passenger loading*	√	√	√
		Reliability*	√	√	√