CHAPTER 9

ANALYTICAL PROCEDURES OVERVIEW

CONTENTS

EXHIBITS

I. INTRODUCTION

In this chapter, a brief overview of the analytical procedures in this manual, their organization into chapters, and guidance on their general application are provided.

The analytical procedures in this manual can be used for a number of applications covering a broad range of facility types. The facility types are distributed among five categories: urban streets, pedestrian and bicycle facilities, highways, freeways, and transit.

Chapters 10–14 of Part II present general concepts

In Chapters 10 through 14, for each of the five categories, general concepts are presented, required inputs for each methodology are identified, reasonable approximations for specific parameters are suggested for use if local data are not available, and example service volume tables are provided. The Part II chapters also contain special procedures used to supplement the planning applications defined in the Part III chapters.

II. OVERVIEW OF ANALYTICAL PROCEDURES

Part III, Chapters 15–27, presents methodologies

For the analytical methods defined in Part III, the calculations of average speed, density, and delay will provide insight into the level of service for what is considered a steady-state condition. This means that the outputs provided by the computational methods are considered representative for the length or area of the analysis and for the duration of the analysis period. Thus, the *Highway Capacity Manual* (HCM) methods are generally not appropriate (unless the analyst performs a special intervention) for the evaluation of inclement weather conditions, accidents or construction activities, queues that are building over both time and space, or the possible effects of vehicle guidance or driver guidance systems typical of intelligent transportation systems. However, some guidelines are identified in Chapter 22 to address these conditions.

The Part III methods have been designed to be sensitive to roadway, traffic, and control characteristics of the facility. However, the methods cannot predict the effects of changes in the posted speed limit, the level of police enforcement, safety features, driver education, or vehicle performance.

A facility is composed of segments and points

A ground transportation system is composed of six modal and facility type subsystems located in a defined study area or corridor. The six subsystems are freeway, urban street, rural highway, transit, pedestrian, and bicycle. Each transportation subsystem is composed of two or more individual facilities. The facilities within each subsystem are all of a single type (freeway, urban street, rural highway) or mode (transit, pedestrian, bicycle). Each facility is in turn made up of segments and points. For example, a freeway contains basic, weaving, and ramp merge/diverge segments. An urban street contains street segments and intersections (points).

A segment is a length of facility where demand and capacity are relatively constant. Each segment begins and ends at a point. Segments are generally directional; for example, each stretch of two-way street is composed of two one-way segments. The exception to this is two-lane highways, where each segment is bidirectional but can be split into two directional segments for analysis. A point is a very short length of facility where demand or capacity changes abruptly from conditions on the upstream or downstream segment.

Analysis of the transportation system proceeds from estimates of travel times and delays at the segment and point levels using the methods described in Part III. Segment and point delays and travel times are converted to total person hours of delay or travel time and then summed to obtain facility estimates.

Part IV, Chapters 28–30, presents corridor and areawide analyses

Part V contains information on simulation and other models

For analyses that combine facility types or that address a corridor or expanded area, the analyst must consult Part IV. Part V contains useful information on applications of simulation and other models to complement the use of HCM 2000 methodologies.

Exhibit 9-1 illustrates the content, by chapter, of the analytical sections of this manual. Outputs from computations based on the methodologies are also indicated.

Most of the analytical processes require estimates of hourly demand in one direction. The section on equivalency of hourly and daily volumes provides guidance on determining directional hourly volumes from average daily traffic volumes. The analytical procedures in Part III (Chapters 15 through 27) require information on the geometric design, control, and demand for the facility being analyzed. The following sections provide some brief guidance on the development of local default values for input data that are difficult to obtain. Generic default values that may be used for specific facility analyses in the absence of local values are provided in Chapters 10 through 14.

Some of the analytical procedures can be quite complex. Analysts may wish to develop tables of maximum service volumes for typical highway facilities in their area. The tables may be used in planning studies to roughly size a facility when resources do not permit more detailed analyses. Guidance on the development of local service volume tables is provided in Appendix B. Examples of service volume tables are given in Chapters 10 through 14.

III. PRECISION AND ACCURACY OF THE MANUAL

The presentation of numerical values and calculations in this manual is based on a long history of evolving methodologies for assessing capacity and quality of service. The first HCM was produced in 1950. It was followed by a series of manuals, the last update being the 1997 HCM. A large number of researchers and research projects in the past 50 years have contributed to the methodologies presented in this, the 2000 edition. To provide a better understanding of the framework in which this edition was developed, the accuracy and precision of numerical values are discussed.

The terms accuracy and precision are independent but complementary concepts. Accuracy relates to achieving a correct answer, while precision relates to the size of the estimation range of the parameter in question. As an example of accuracy, consider a method that is applied to estimate a performance measure. If the performance measure is delay, an accurate method would provide an estimate closely approximating the actual delay that occurs under field conditions. The precision of such an estimate is the range that would be acceptable from an analyst's perspective in providing an accurate estimate. Such a range might be expressed as the central value for the estimated delay plus or minus several seconds. In general, the inputs used for the methodologies in this manual are from field observations or estimates of future conditions. In either case, and particularly for future conditions, the inputs can only be expected to be accurate to within 5 or 10 percent of the true value. Thus, the computations performed cannot be expected to be extremely accurate, and the final results must be considered as estimates that are accurate and precise only within the limits of the input values used.

To provide numerical values and computational results that are relatively easy to use and that indicate the presumed accuracy and precision, a framework of guidelines was established during preparation of this manual. In the following sections, an explanation of this framework is given.

PRECISION AND ACCURACY FRAMEWORK

The user of the HCM should be aware of the limitations of the accuracy and precision of the methodologies in the manual. Such awareness will help the user to interpret the results of an analysis and to use the results to make a decision on design or operation of a transportation facility.

Many of the models in the HCM are based on theoretically derived relationships, which include assumptions and contain parameters that must be calibrated on the basis of field data. Other models in the HCM are primarily statistical. Both types require data collected at a sampling of sites. The degree to which the models reflect reality is often stated in terms of the accuracy and precision of the model. Accuracy and precision are terms used to express the probable error associated with an estimate.

Frequently, after a model is developed, it is validated by comparing the estimates from the model with values measured in the field from an independent set of sites. A regression line fitted to the plot of points for field-measured versus model-estimated values will result in a line with a slope different from 45 degrees. The difference can be considered the relative accuracy of the model. The dispersion of the points around the regression line can be considered the precision of the model. The measure of dispersion with which many analysts are familiar is the R^2 value. These statistics, based on field and predicted data, indicate the limitations of the models in predicting with great precision and accuracy.

Few of the models in the HCM have well-documented measures of accuracy and precision. Typically, when research is completed and statistical relationships are reported, the Committee on Highway Capacity and Quality of Service will exercise its judgment in modifying the results.

Several factors result in limitation on the accuracy and precision of HCM analysis

Prediction error from other sources may also result when the user applies the HCM. For example, the accuracy of results may be reduced by the use of default values for one or more of the parameters in the models. In addition, there are limitations on the accuracy and precision of traffic inputs used in these models. Traffic measurements and predictions, including magnitude and mix of traffic, have inherent limitations on accuracy.

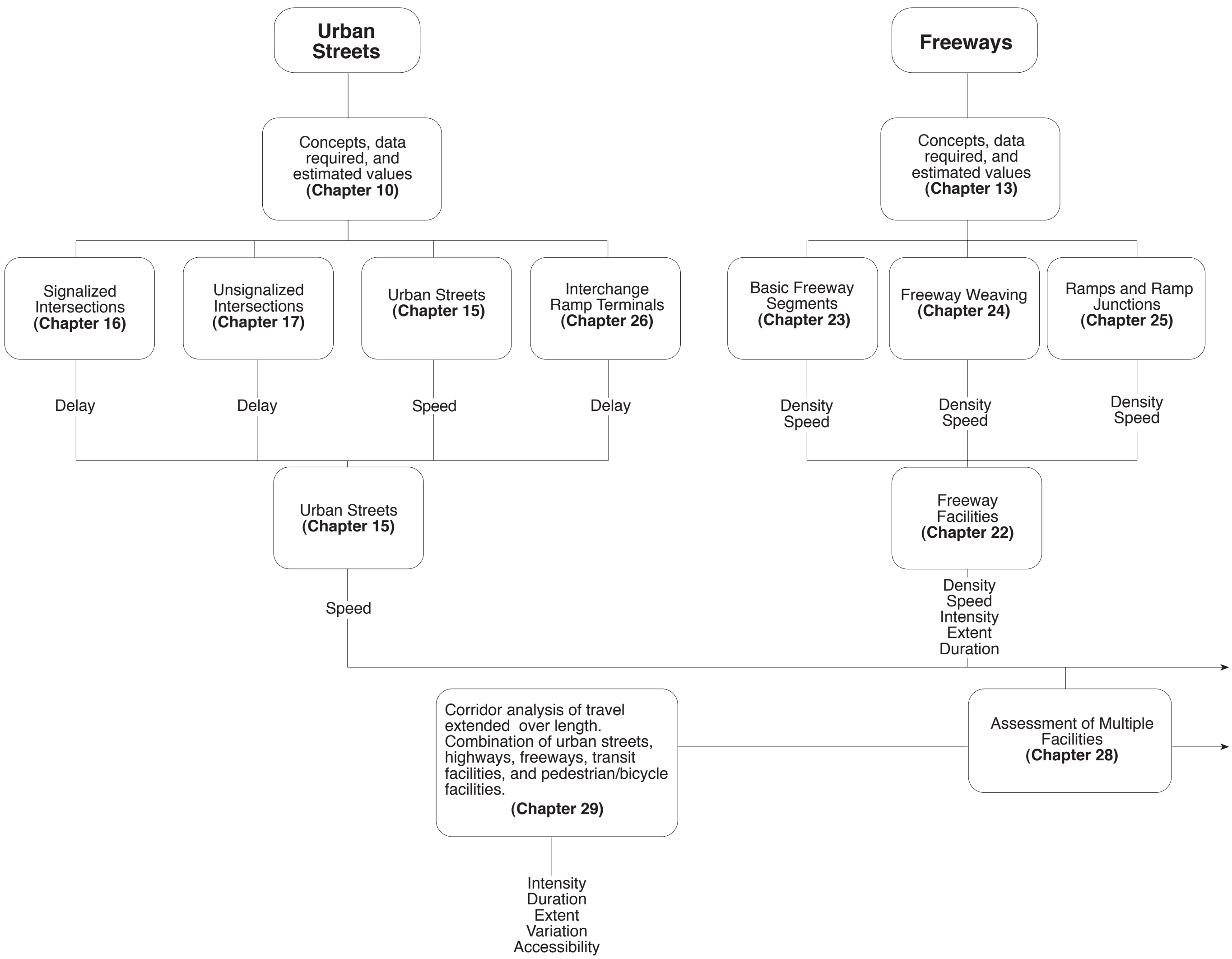
The limitations on the accuracy and validity of predictions of performance measures should be recognized in applying the results of an analysis. For instance, small differences between the values of performance measures for alternative designs should not always be assumed to be real (statistically significant) differences. Furthermore, if the predicted value for a measure of effectiveness is near, but below, a critical threshold, there is some probability that it will in fact be higher than predicted and exceed the critical threshold. The HCM user should recognize, therefore, that judgment is required in applying the results of analyses. One basis for that judgment is a good understanding of the structure and basis of the models used in this manual.

Constraint of Prior Research Results

Research precision and accuracy

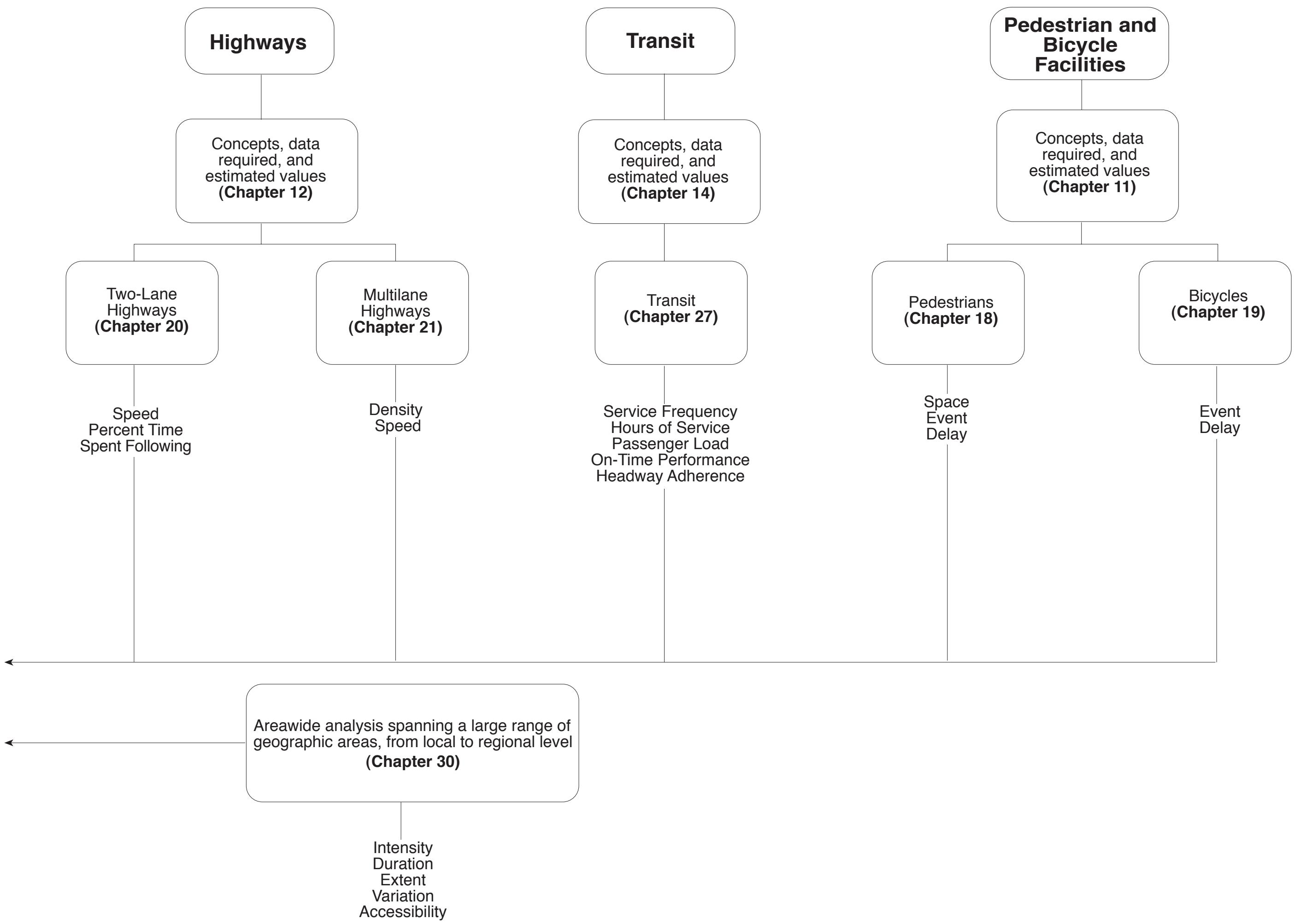
The methodologies in this manual have been developed by a number of researchers working on many research projects. Few of these projects have presented results with accompanying statements on precision and accuracy. Rather, most of the methods have involved the use of mean or average values for parameters. Results have been presented in a variety of forms with regard to the use of tables, graphs, and interpolated values. The number of digits to the right of the decimal point in factors, calculated values of performance measures, and threshold values used to define level of service has also varied. In general, it was considered prudent to follow the presented results and the significant figures used in prior research rather than to change the recommended values arbitrarily. Whenever possible, the tabulated factors and adjustments and the final calculated values of performance measures used in the reported research were maintained for the methods in this manual.

Exhibit 9-1. Structure of HCM 2000 Methodologies



Discussion of simulation models and their applications with numerical exercises (Chapter 31).

Exhibit 9-1 (continued). Structure of HCM 2000 Methodologies



Precision in calculation differs from precision in presenting final results

Calculation Precision Versus Display Precision

The extensive use of personal computers has allowed calculations of capacity and level of service to be carried to a large number of digits to the right of the decimal point. Because of this ease of calculation, there is a need to state clearly that the final result of calculations done manually and carried to the suggested number of significant figures might be slightly different from the result of calculations performed on a computer. This difference has been explicitly recognized in this manual. For example, lists of factors are often displayed with three or four digits to the right of the decimal point to more closely adhere to the calculation protocol inherent in computers.

Implied Precision from Displayed Results

The typical interpretation given to a value such as 2.0 is that the value is in a precision range of two significant figures and that results from calculations should be rounded to this level of precision. Occasionally, particularly in the running text of the manual, editorial flexibility allows a zero to be dropped from the number of digits. In most cases, however, the number of the digits to the right of the decimal point does imply that a factor or numerical value has been calculated to that level of precision.

Directives from TRB Committee

Prior to publication of this manual, the Committee on Highway Capacity and Quality of Service (A3A10) developed guidelines for the presentation of results. The guidelines were presented in mid-1997 in the form of advice to the preparers of this manual. Several recommendations were included and were particularly aimed at the exhibits and values shown and used in Chapter 16, Signalized Intersections. This advice was considered, along with the factors mentioned above, in developing the HCM.

Conventions for display of results in the HCM

Specific Components for Presentation Guideline

The overall objective of the guideline is to present tabular values and calculated results in a consistent manner throughout the manual. Another objective is to use a number of significant digits that is reasonable and indicates to the analyst that the results are not extremely precise but take on the precision and accuracy associated with the input variables. As stated earlier, such accuracies for traffic volume counts and measurement of geometric conditions seldom are better than a central value plus or minus 5 percent. Prediction to a future time frame presents even greater differences between the assumed input values and what will actually occur at that time horizon. The guideline for this manual recognizes that rounding intermediate results in a series of calculations for a given method is not appropriate and can be more confusing than worthwhile. The third objective of the guideline is that prior research results, advice, and recommendations of the Committee on Highway Capacity and Quality of Service and the standard practice of the profession in these calculations are to be respected.

Input Values

Following is a list of representative (not exhaustive) input variables and the suggested number of digits for each.

- Volume (whole number);
- Grade (whole number);
- Lane width (one decimal place);
- Percentage of heavy vehicles (whole number);
- Peak-hour factor (two decimal places);
- Arrival type (category, 1 to 6);
- Pedestrian volume (whole number);
- Bicycle volume (whole number);
- Parking maneuvers (whole number);

- Bus stopping (whole number);
- Green, yellow, all-red, and cycle times (one decimal place);
- Lost time/phase (whole number); and
- Minimum pedestrian time (one decimal place).

Adjustment Factors

Factors interpolated from tabular material can use one more decimal place than presented in the table. Factors generated from equations can be taken to three decimal places.

Example Service Volume Tables

In rounding volumes for service volume tables, a precision of no greater than the nearest 10 vehicles or passenger cars should be used. Rounding to the nearest 50 or 100 (three significant digits) is strongly recommended if threshold values determining specific levels of service are not affected.

Free-Flow Speed

For base free-flow speeds, show the value to the nearest 1 km/h. For free-flow speeds that have been adjusted for various conditions and are thus considered an intermediate calculation, show speed to the nearest 0.1 km/h.

Speeds

For threshold values that define levels of service, show speed to the nearest 1 km/h. For intermediate calculations of speed, use one decimal place.

Volume to Capacity Ratios

Show v/c ratios with two decimal places.

Delay

In computing delay, show results with one decimal place. In presenting delay as a threshold value in level-of-service tables, show a whole number.

Pedestrian Space

To conform with recommended research results, show pedestrian space values with one decimal place.

Occurrences and Events

For all event-based items, use values to a whole number. These items include parking maneuvers, bus stops, events along a pedestrian or bicycle path, and number of cycles in a given time period.

General Factors

In performing all calculations on a computer, the full precision available should be used. Intermediate calculation outputs should be displayed to three significant digits throughout. For the measure that defines level of service, the number of significant digits presented should exceed by one the number of significant digits shown in the level-of-service table.

Displayed Results

For the example problems of Part III, manual calculations were performed. Once the value of an intermediate calculation is entered into a worksheet, that rounded value is used for all remaining calculations. As the computations progress, the analyst may round the values to indicate that the precision of the final results is less than implied by the intermediate calculations. The analyst can refer to the example problems of Chapters 16 and 21 for specific examples of rounding and display of calculations and results for interrupted- and uninterrupted-flow facilities, respectively.

AVERAGE VALUES

Concept of an average value

Three concepts are implicit in all of the material presented in this manual, and they should be understood by HCM users. Unless otherwise noted or defined, numerical values are mean values for the given parameter. Thus, a measure of speed or delay is the mean value for the population of vehicles (or persons) being analyzed. Similarly, a lane width for two or more lanes is the mean (average) width of the lanes. The word “average” or “mean” is only occasionally carried along in the text or exhibits to reinforce this otherwise implicit fact.

The terms demand and volume tend to be used interchangeably in this manual for undersaturated flow conditions. For oversaturated conditions, when demand is greater than capacity, demand is the appropriate term. Several chapters in Part III, including Chapter 16, “Signalized Intersections,” and Chapter 22, “Freeway Facilities,” address the condition of demand being greater than capacity.

Another significant concept implicit in these materials is that the level-of-service threshold values, the adjustment factors used in the computations, and the calculated values of performance measures are assumed to represent conditions that have a reasonable expectation of being observed regularly in North America rather than the most extreme that might be encountered.

SENSITIVITY TO INPUT VARIABLES

Impact of input quality on results

The analyst should recognize that the quality of the results depends on the quality of the input data. Default values will produce less accurate results than field-measured data. Generic default values suggested in this manual will produce less accurate results than locally developed default values.

IV. HOURLY AND DAILY VOLUME EQUIVALENCIES

Capacity and other traffic analyses frequently focus on the peak hour of traffic for the peak direction because it represents high capacity requirements. Because planning applications frequently deal with annual average daily traffic (AADT), three important factors (K, D, and PHF) are needed to provide a means to convert between daily and hourly directional volumes. These factors are discussed in greater detail in Chapter 8, and their general application is presented below.

Calculation of analysis period flow

Most of the procedures in this manual are based on peak 15-min flow rates. Because traffic does not flow evenly over an hour, subhourly peaking should be accounted for when the analysis is in terms other than 15-min flows. The relationship between the peak 15-min flow rate and the full hourly volume is given by the peak-hour factor (PHF). To convert peak 15-min flow rates to hourly volumes, the flow rate is multiplied by the PHF.

For vehicle traffic, the proportion of AADT occurring in the analysis hour is referred to as the K-factor. As presented in Chapter 8, the K-factor is highly dependent on the analysis hour selected, the specific characteristics of the roadway, and the location of the roadway. In converting hourly volumes to daily volumes, the hourly volume is divided by the K-factor. During any particular hour, traffic volume will likely be greater in one direction than in the other. Directional distribution (D) is an important factor in capacity and quality of service analysis. To convert hourly directional volumes to daily volumes, the hourly directional volumes are divided by the D-factor. For planning and design applications, AADT is typically given. To convert the AADT to an equivalent hourly volume, the AADT is multiplied by both the K-factor and the D-factor.

Most of the analytical procedures use the peak 15-min flow rate. This rate is obtained by dividing the hourly volume by the PHF. Service volume results, expressed in 15-min flow rates, must be multiplied by the PHF to obtain the equivalent hourly volume. This has been done, where appropriate, for the example service volume tables in Chapters 10 through 14, so that all volumes shown are equivalent hourly volumes. Exhibit 9-2 gives default values for K, D, and PHF that may be used in the absence of local field data.

EXHIBIT 9-2. TYPICAL DEFAULT VALUES FOR PHF, K, AND D

Factor	Area	
	Urban	Rural
PHF	0.92	0.88
K	0.09	0.10
D	0.60	0.60

V. USE OF DEFAULT VALUES

Alternative if no field data can be obtained

Planning applications of the computation methods are described in Part III. Guidance for estimating input values and selecting default values for planning applications is given in Part II (Chapters 10 through 14). The analyst should observe the following suggestions when generating inputs to the analytical procedures.

- If the input variable can be observed in the field, measure it in the field.
- In performing a planning application for a facility not yet built, measure a similar facility in the area that has conditions similar to those of the proposed facility.
- If neither of the first two sources is available, rely on local policy or typical local/state values.
- If none of the above sources is available, default values provided in Part II (Chapters 10 through 14) of this manual may be used.

The development of local default values is discussed in Appendix A.

VI. SERVICE VOLUME TABLES

Service volume tables are valid only under the conditions for which they were developed

The methods in this manual are frequently applied to identify the operating level of service given a demand volume of traffic. Conversely, the analyst often desires to know the maximum service volume for a facility operating with a specific level of service. Service volume tables can be prepared to facilitate this type of analysis. Such tables use locally generated default values (or, alternatively, defaults suggested in this manual) for most or all of the required inputs. The analyst performs a series of computations to fill in the tabular values. Caution should be used in applying service volume tables because of the assumptions made in generating the tables. Footnotes to the service volume tables describe the assumptions used to generate the values. Appendix B explains the steps involved. Note that service volume tables for various facility types are included in Chapters 10 through 14. Other examples of service volume tables can be found in Florida's *Level of Service Handbook* (*1*).

VII. REFERENCE

1. *Level of Service Handbook*. System Planning Office, Florida Department of Transportation, Tallahassee, 1998.

APPENDIX A. DEVELOPING LOCAL DEFAULTS

How to establish default values for local conditions

The best method for determining local default values for traffic parameters is to measure a sample of facilities in the field. If this is not feasible, an informal survey of local highway operating agencies can be conducted to determine their standard design practices for new facilities and the condition of the facilities currently in place. Facilities can be stratified by area type and facility type to ensure reliable default values. The choice of categories is a local decision. Exhibit A9-1 provides an example framework for stratifying defaults.

EXHIBIT A9-1. EXAMPLE DEFAULT STRATIFICATION SCHEME

Area Type	Facility Type					
	Interstate Freeway	Other Freeway	State Highway	Non–State Highway	Principal Arterials	Minor Arterials/ Collectors
Central business district						
Suburban						
Rural						

The default value for each category is the arithmetic mean of the observations. The variation in the observed value for each category should be compared with the difference in the means for each category. Analysis of variance techniques can be used to determine whether categories should be consolidated. Note that the stratification framework can be used for roadway, traffic, and control parameters.

The sample size required for each category is determined by the desired accuracy in the resulting input estimate and the variation in the observed values. Equation A9-1, adapted from a statistics textbook (*1*), gives the minimum sample size that will allow the analyst to compute the mean and estimate the margin of error in the estimated mean with 90 percent or better confidence.

$$n \geq \frac{4s^2}{(\xi)^2} \qquad \text{(A9-1)}$$

where

n = minimum number of observations to meet accuracy goal for mean;
ξ = maximum desirable error in the estimate of the mean (at the desired confidence level); and
s = estimated standard deviation for the sample, computed using Equation A9-2.

$$s^2 = \frac{\Sigma(x_i - \bar{x})^2}{(n-1)} \qquad \text{(A9-2)}$$

where

x_i = ith observation of the value, and
$\bar{x}$ = mean value of the observations.

For sample sizes less than 5, the equation will provide less than 90 percent confidence in the margin of error. A higher confidence level can be obtained by substituting $2t(s^2)$ for $4(s^2)$ in the equation, where t is the Student's t-statistic for the desired confidence level.

In practice, one does not know whether an adequate sample size has been obtained until after the data have been collected and the sample variance has been computed. However, the analyst can use prior experience to estimate the likely standard deviation.

To demonstrate the use of Equation A9-1, assume that a local base saturation flow rate is desired. Fifteen observations of prevailing saturation flow rates (see Appendix H of Chapter 16 for methodology) have been collected at four local intersections. The standard deviation of the sample is 45. It has been determined that the maximum desirable estimated error in the mean is 5 percent. Are more than the initial 15 observations needed, and if so, how many are required in total?

$$s = 45$$

$$\xi = 5$$

$$n \geq \frac{4s^2}{(\xi)^2} = \frac{4 * (45)^2}{(5)^2} = 324$$

Therefore, 15 observations are not enough. At least 324 observations are needed.

REFERENCE

1. Wonnacott, T. H., and R. J. Wonnacott. *Introductory Statistics for Business and Economics*. John Wiley and Sons, New York, 1990.

APPENDIX B. DEVELOPING SERVICE VOLUME TABLES

A methodology for developing service volume tables

Service volume tables can be generated by facility type and area type by using the estimated values and appropriate software to back-solve for the maximum volumes for each level of service. The procedure is as follows:

1. Determine all nonvolume input values to be used in developing the service volume table. Develop categories of facilities and area types and select input values (e.g., PHF, percentage of heavy vehicles, urban area, suburban area) to be used. Repeat the following steps for each facility and area category.
2. Identify the range in the number of lanes to be tested.
3. Identify the desired level of service (LOS) measure of effectiveness values for LOS A through E from the chapters of Part III (for example, a density of 10 pc/km/ln is the maximum density for LOS A for a basic freeway segment).
4. Select the first category of facility type, area type, and the number of lanes for which to compute the maximum service volumes.
5. Start the search for the maximum service volume for the LOS A threshold according to the appropriate methodology.
6. Compute the LOS measure (i.e., delay, speed, or density) for the first iteration volume (lower volume than the LOS A threshold) (label this Vol 1).
7. If the result exceeds the LOS A threshold value, then LOS A is unachievable. Go to the next higher LOS threshold (for LOS B) and repeat Steps 5, 6, and 7 until an achievable LOS is found. Then go on to the next steps.
8. Select a second iteration volume (label this Vol 2).
9. Compute the LOS measure (delay, speed, or density).
10. If the resulting LOS measure is lower than the LOS threshold, repeat Steps 1 and 2 with a volume twice the original estimate. Repeat until the volume is found to be greater than the desired LOS threshold.

11. Use the bisection method (or another more efficient numerical method) to progressively narrow the uncertainty in the service volume until it is within the desired bounds. The following steps describe the bisection method (*1*).

12. Compute the volume halfway between Vol 1 and Vol 2. Label this volume Vol 3.

13. Compute the LOS measure (delay, speed, or density) for Vol 3.

14. If the LOS result for Vol 3 is higher than the desired LOS threshold, drop Vol 1 and relabel Vol 3 as the new Vol 1.

15. If the LOS result for Vol 3 is lower than the desired LOS threshold, drop Vol 2 and relabel Vol 3 as the new Vol 2.

16. Is the range between Vol 1 and Vol 2 acceptable? If so, stop and use the average of Vol 1 and Vol 2 as the service volume estimate. If not, repeat Steps 12 through 16.

REFERENCE

1. Courage, K. G., and J. Z.-Y. Luh. Computation of Signalized Intersection Service Volumes Using the 1985 Highway Capacity Manual. In *Transportation Research Record 1194*, TRB, National Research Council, Washington, D.C., 1988, pp. 179–190.