CHAPTER 5
QUALITY AND LEVEL-OF-SERVICE CONCEPTS

CONTENTS

LIST OF EXHIBITS

1. INTRODUCTION

OVERVIEW

There are many ways to measure the performance of a transportation facility or service—and many points of view that can be considered in deciding which measurements to make. The agency operating a roadway, automobile drivers, pedestrians, bicyclists, bus passengers, decision makers, and the community at large all have their own perspectives on how a roadway or service should perform and what constitutes "good" performance. As a result, there is no one right way to measure and interpret performance.

Quality of service describes how well a transportation facility or service operates from the traveler's perspective. *Level of service* (LOS) is a quantitative stratification of a performance measure or measures representing quality of service. The LOS concept facilitates the presentation of results through the use of a familiar A (best) to F (worst) scale. LOS for a given mode on a given transportation system element is defined by one or more *service measures*. Service measures are identified from the range of performance measures that the *Highway Capacity Manual* (HCM) can estimate as the measures that (*a*) best describe operations, (*b*) best reflect the traveler perspective, and (*c*) are useful to roadway operating agencies.

CHAPTER ORGANIZATION

Three overarching concepts—quality of service, LOS, and service measures—are the subjects of Chapter 5:

- Section 2 lists the variety of factors that affect traveler perceptions of service quality and contrasts them with the topic areas that are covered in the HCM.
- Section 3 introduces the LOS concept, describes how to apply LOS as part of an analysis, and emphasizes the need to consider additional performance measures to obtain a full picture of operating conditions.
- Section 4 describes how service measures are selected, explains how LOS F is defined, and introduces the service measures used in the HCM for each system element and mode.

2. QUALITY OF SERVICE

Quality of service defined.

Quality of service describes how well a transportation facility or service operates from a traveler's perspective. Quality of service can be assessed in a number of ways. Among them are directly observing factors perceivable by and important to travelers (e.g., speed or delay), surveying travelers, tracking complaints and compliments about roadway conditions, forecasting traveler satisfaction by using models derived from past traveler surveys, and observing services not directly perceived by travelers (e.g., average incident clearance time) that affect measures they can perceive (e.g., speed, arrival time at work).

Factors that influence traveler-perceived quality of service include

- Travel time, speed, and delay;
- Number of stops incurred;
- Travel time reliability;
- Maneuverability (e.g., ease of lane changing, percent time-spent-following other vehicles);
- Comfort (e.g., bicycle and pedestrian interaction with and separation from traffic, transit vehicle crowding, pavement quality);
- Convenience (e.g., directness of route, frequency of transit service);
- Safety (actual or perceived);
- User cost;
- Availability of facilities and services;
- Facility aesthetics; and
- Information availability (e.g., highway wayfinding signage, transit route and schedule information).

The HCM provides tools for measuring the multimodal operations aspects of quality of service.

The HCM's scope, measuring the multimodal performance of highway and street facilities, is narrower than the quality-of-service aspects listed above. As discussed in Chapter 1, HCM User's Guide, companion documents to the HCM address highway safety, roadway design, and wayfinding signage, among other topics. The HCM focuses particularly on the travel time, speed, delay, reliability, maneuverability, and comfort aspects of quality of service, although a limited number of the HCM's performance measures address some of the other aspects listed above.

LOS is an important tool used by the HCM to stratify quality of service.

The HCM provides a variety of performance measures in Volumes 2 and 3 to assess the quality of service of transportation system elements. These measures can be directly observed in the field or estimated from related field-observed factors. LOS is the stratification of one or more performance measures selected to represent quality of service and is the topic of the next section.

3. LEVEL OF SERVICE

DEFINITION

LOS defined.

LOS is a quantitative stratification of a performance measure or measures representing quality of service. The measures used to determine LOS for transportation system elements are called *service measures*. The HCM defines six levels of service, ranging from A to F, for each service measure or combination of service measures. LOS A represents the best operating conditions from the traveler's perspective and LOS F the worst. For cost, environmental impact, and other reasons, roadways are typically designed not to provide LOS A conditions during peak periods but instead to provide some lower LOS that balances individual travelers' desires against society's desires and financial resources. Nevertheless, during low-volume periods of the day, a system element may operate at LOS A.

LOS is measured on an A–F scale. LOS A represents the best operating conditions from a traveler's perspective.

USAGE

LOS is used to translate complex numerical performance results into a simple A–F system representative of travelers' perceptions of the quality of service provided by a facility or service. Practitioners and decision makers alike must understand that the LOS letter result hides much of the complexity of facility performance. This feature is intended to simplify decision making on whether facility performance is generally acceptable and whether a future change in performance is likely to be perceived as significant by the general public. The language of LOS provides a common set of definitions that transportation engineers and planners can use to describe operating conditions; however, the appropriate LOS for a given system element in the community is a decision for local policy makers. One reason for the widespread adoption of the LOS concept by transportation agencies is the concept's ability to communicate roadway performance to nontechnical decision makers. However, LOS has other strengths and weaknesses, described below, that both analysts and decision makers need to be mindful of.

LOS is a useful and widely adopted tool for communicating roadway performance to laypersons and decision makers. However, its strengths and weaknesses should be kept in mind.

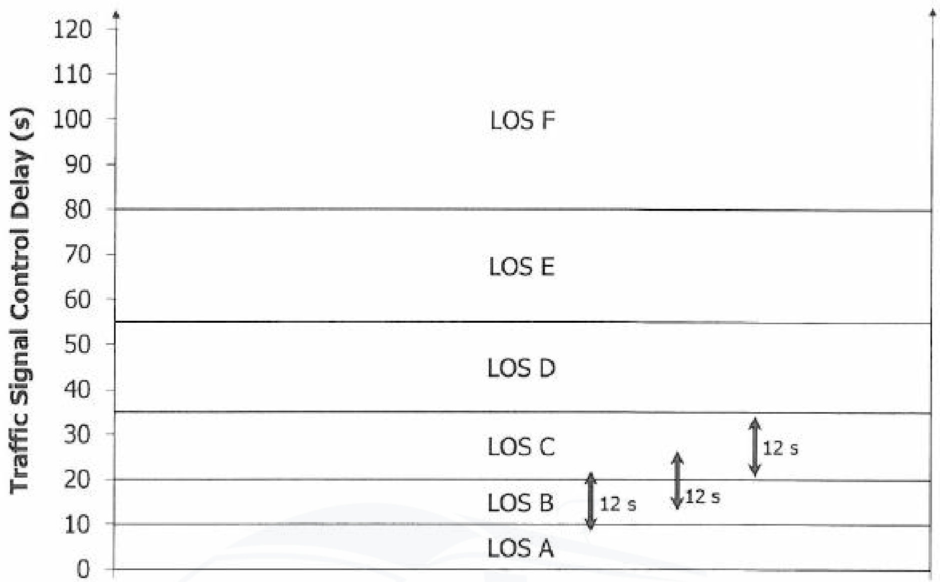
Understanding the Step Function Nature of LOS

LOS is a step function. An increase in average control delay of 12 s at a traffic signal, for example, may result in no change in LOS, a drop of one level, or even a drop of two levels, depending on the starting value of delay, as illustrated in Exhibit 5-1.

A step function provides a constant result through a range of input values and then changes abruptly to provide a new constant result after a threshold input value is reached.

From a traveler perception standpoint, the condition shown in Exhibit 5-1 is not necessarily inconsistent. A change of LOS indicates that roadway performance has transitioned from one range of traveler-perceivable conditions to another range, while no change in LOS indicates that conditions have remained within the same performance range as before. Service measure values indicate where conditions lie within a particular performance range. Because a small change in a service measure (e.g., a 2-s change in delay) can result in a change from one LOS to another, the LOS letter result can imply a more significant or perceptible change than actually occurred.

Exhibit 5-1
Example of the Step Function Nature of LOS



Identical changes in the service measure value may result in no change in LOS or a change of one or more levels of service, depending on how close the starting value is to a LOS threshold.

Defining performance standards on the basis of LOS (or any fixed numerical value) means that small changes in performance can sometimes result in the standard being exceeded, when a facility is already operating close to the standard.

This aspect of LOS can be a particularly sensitive issue when transportation agencies define their operational performance standards solely by using LOS. The definition of any fixed standard, whether numerically or as a LOS letter, always entails the possibility that a small change in performance may trigger the need for potentially costly improvements.

Variability of the Inputs to LOS

Section 2 of Chapter 7, Interpreting HCM and Alternative Tool Results, discusses sources of uncertainty and their impacts on analysis results in more detail.

Although computer software that implements HCM methodologies can sometimes report results to many decimal places, three major sources of uncertainty influence service measure values and, thus, the LOS result:

1. The models used to estimate service measure values have confidence intervals associated with their outputs.
2. The models may, in turn, rely on the output of other models that have their own associated confidence intervals.
3. The accuracy of input variables, such as demand flow rate, is taken to be absolute when, in fact, there is a substantial stochastic (i.e., random) variation around the measured values.

Models provide a best estimate of service measure values, but the "true" value likely lies within a confidence interval range above or below the estimated value.

Thus, any reported service measure value, whether resulting from an HCM methodology, an alternative tool, or field measurement, potentially has an associated range within which the "true" value lies. The LOS concept helps to downplay the implied accuracy of a numerical result by presenting a range of service measure results as being reasonably equivalent from a traveler's point of view. Nevertheless, the variability issues also mean that the "true" LOS value may be different from the one predicted by a methodology. In addition, for any given set of conditions, different travelers may perceive their LOS to be different from one another, as well as different from the LOS estimated by an HCM method. One way of thinking about reported service measure values and the corresponding LOS result is that they are the statistical "best estimators" of conditions and aggregate traveler perception.

Beyond LOS F

The HCM does not subdivide LOS F, but several measures are available to describe the severity of a LOS F condition.

The HCM uses LOS F to define operations that have either broken down (i.e., demand exceeds capacity) or have reached a point that most users would consider unsatisfactory, as described by a specified service measure value (or combination of service measure values). However, analysts may be interested in knowing just how bad the LOS F condition is, particularly for planning applications where different alternatives may be compared. Several measures are available for describing individually, or in combination, the severity of a LOS F condition:

- *Demand-to-capacity ratios* describe the extent to which demand exceeds capacity during the analysis period (e.g., by 1%, 15%).
- *Duration of LOS F* describes how long the condition persists (e.g., 15 min, 1 h, 3 h).
- *Spatial extent measures* describe the areas affected by LOS F conditions. They include measures such as the back of queue and the identification of the specific intersection approaches or system elements experiencing LOS F conditions.

Separate LOS Reporting by Mode and System Element

LOS is reported separately, by mode, for a given system element.

LOS is reported separately for each mode for a given system element. Each mode's travelers have different perspectives and could experience different conditions while traveling along a given roadway. Reporting LOS separately by mode also assists in assessing multimodal trade-offs when design options are evaluated. In contrast, use of a blended LOS risks overlooking quality of service deficiencies that discourage the use of nonautomobile modes, particularly if the blended LOS is weighted by the number of modal travelers. Other measures, such as person delay, can be used when an analysis requires a combined measure.

Identical values of some service measures (e.g., delay) can produce different LOS results, depending on the system element to which the service measure is applied. The Transportation Research Board (TRB) Committee on Highway Capacity and Quality of Service (HCQS Committee) believes that travelers' expectation of performance varies at different system elements but recognizes that further research is needed to understand fully the variation in traveler perceptions of LOS across facility types.

LOS as Part of a Bigger Picture

No single performance measure tells the full story of roadway performance.

Neither LOS nor any other single performance measure tells the full story of roadway performance. Depending on the particulars of a given analysis, queue lengths, demand-to-capacity ratios, average travel speeds, indicators of safety, quantities of persons and vehicles served, and other performance measures may be just as or even more important to consider, whether or not they are specifically called out in an agency standard. For this reason, the HCM provides methods for estimating a variety of useful roadway operations performance measures, not just methods for determining LOS. Chapter 7, Interpreting HCM and Alternative Tool Results, lists the major performance measures available from each chapter of Volumes 2 and 3.

Duration of an operating condition can be important, since it helps describe the severity of the condition (e.g., the duration of a LOS F condition). In cases where demand exceeds capacity, duration *must* be known so that the analysis period is long enough to allow all demand to be served and all relevant performance measures to be calculated properly. The frequency and probability of a particular condition occurring (e.g., likelihood or frequency of queue storage being exceeded during an analysis period) are also useful descriptors.

4. SERVICE MEASURES

DEFINITION AND CHARACTERISTICS

Service measures described.

Service measures are performance measures used to define LOS for transportation system elements.

Ideally, service measures should exhibit the following characteristics:

- Service measures should reflect travelers' perceptions (i.e., measures should reflect things travelers can perceive during their journey).
- Service measures should be useful to operating agencies (e.g., agency actions should be able to influence future LOS).
- Service measures should be directly measurable in the field (e.g., an analyst wishing to determine LOS for a two-lane highway used for recreational access can go into the field and directly measure average travel speed).
- Service measures should be estimable given a set of known or forecast conditions (e.g., a method is provided for estimating the average travel speed on a two-lane highway, given inputs for roadway and traffic conditions).

SERVICE MEASURE SELECTION

Service measure and threshold selection.

Historically, the selection of a service measure or measures for an analysis methodology has been based on the collective opinion and judgment of TRB's HCQS Committee. The service measure threshold values that identify the breakpoints between each LOS have also been determined by the HCQS Committee's consensus identification of points at which discernible changes in conditions, performance, or user perceptions occur. In some cases, the conditions represented by individual LOS letters are specifically described in the methodological chapters in Volumes 2 and 3.

The approach described above has been necessary because until 1993 little information had been available on the evaluation of operating conditions by travelers. The intent of the committee has been to select service measures that it believed would be highly correlated with travelers' personal assessments of the operating conditions. Since 1993, considerably more research has been focused on determining appropriate service measures directly on the basis of traveler input. This area of research was still immature at the time of publication of this edition of the HCM. The HCQS Committee intends to monitor and evaluate future research in this area for potential inclusion in subsequent editions.

Studies that seek to determine service measures and thresholds on the basis of traveler perceptions use research approaches that directly involve a sample of travelers. Some of the methods used to obtain this direct traveler input include in-field experiments (e.g., driving or bicycling courses), simulated in-field experiments (e.g., use of video presentations), focus groups, and surveys. The study participants are typically asked to rate the conditions they are presented with on a scale of "very good" to "very poor," or something similar. The qualitative ratings are later converted to numeric values for analysis purposes.

Some challenges to these types of studies include designing the instrument (e.g., field experiment, focus group) to capture all of the roadway, traffic, and control factors that might affect travelers' perceptions of operating conditions; excluding factors that may not be relevant but could distract study subjects; recruiting an adequate sample of study participants from both quantity and diversity perspectives; replicating desired conditions (for in-field experiments) for repeated observations; and accounting for the distribution of LOS responses that will result from each test scenario in the analysis methodology.

The advantage of this type of research approach is that, with application of an appropriate analysis methodology, multiple variables can be considered simultaneously, consistent with the high likelihood that travelers consider multiple factors when they evaluate operating conditions. Including multiple factors also gives agencies more options in seeking to achieve a desired LOS for a given mode or in balancing the needs of various modes.

Variables found to be statistically significant in predicting travelers' perceptions are incorporated into a mathematical function (hereinafter referred to as a *model*). In the model, the coefficients (i.e., weighting factors) associated with each of the variables are determined directly through a statistical analysis. The output from such a model is a value often referred to as a LOS score. The LOS score value generally represents the average score that travelers would give a facility or service. Furthermore, some of the HCM methodologies can directly estimate the threshold values between LOS letters, again, on the basis of traveler input. In determining the LOS letter, the LOS score value is compared with the statistically estimated threshold values.

Any number of factors can be included in this type of model, but for models to be useful from a practical perspective, only variables representing operational or design conditions are usually included. Operational conditions refer to variables such as delay and speed, while design conditions refer to variables such as median type and sidewalk presence. Traveler characteristics (e.g., age, gender, income) can affect LOS perceptions; however, these data are difficult to collect in a transportation engineering context. Thus, their utility in a LOS model is limited.

Several methodological approaches have been applied to relate traveler perceptions directly to LOS, including regression-based methods (*1–4*), ordered probit models (*5, 6*), and fuzzy clustering (*7*). These studies have addressed facilities such as urban and rural freeways, arterial streets, and signalized intersections. LOS methods resulting from some of these studies have been included in the HCM 2010, while others have been studied by the HCQS Committee to improve the understanding of techniques used in estimating traveler-based LOS.

The HCM's bicycle, pedestrian, and transit methods generally apply LOS measures based directly on traveler perceptions.

The HCM 2010 is the first HCM edition to incorporate LOS methodologies that are based directly on results from traveler perceptions of LOS. As research into traveler perception of LOS continues to mature and results from regional studies are validated nationally, the HCQS Committee expects to continue to include new LOS methodologies in future editions of the HCM. When research is not available to support traveler-perceived LOS methodologies, HCQS Committee–selected service measures and thresholds continue to be used.

DETERMINATION OF LOS F

The threshold between LOS E and LOS F is based on the judgment of the HCQS Committee in some instances and is determined directly from research on traveler perceptions of LOS in others. For example, in the case of basic freeway segments, the service measure and LOS thresholds were determined by the HCQS Committee; density was selected as the service measure and the LOS E–F density threshold value was selected as the density at which traffic flow transitions from undersaturated to oversaturated. In the case of bicycling on urban streets, the service measures were determined from research on traveler perception of LOS; the LOS E–F threshold was chosen as a value that represents the transition to a totally unacceptable condition (i.e., an average bicyclist will not ride under these conditions).

Thresholds between LOS A and E may be based on ranges of values that define particular operating conditions or may simply provide an even gradation of values from LOS A to E. As mentioned previously, in some studies on traveler perceptions of LOS, the methodological approach explicitly yields the model variables (e.g., speed, median presence) as well as the specific LOS thresholds. However, these thresholds are still a function of the total number of LOS categories originally included in the study.

A v/c ratio greater than 1.0 (capacity) is often used to define LOS F conditions.

The volume-to-capacity (v/c) ratio, or more correctly, demand-to-capacity (d/c) ratio, is a special-case service measure. It cannot easily be measured in the field, nor is it a measure of traveler perceptions. Until capacity is reached (i.e., when flow breaks down on uninterrupted-flow facilities and when queues build on interrupted- or uninterrupted-flow facilities), these ratios are not perceivable by travelers. Therefore, the HCM often uses a v/c (d/c) ratio of greater than 1.0 (i.e., capacity) as an additional test for defining when LOS F occurs but does not use these ratios to define other LOS ranges.

SERVICE MEASURES FOR SPECIFIC SYSTEM ELEMENTS

Crosscutting Issues

Motorized Vehicle Mode

LOS for the motorized vehicle mode reflects automobile driver perspectives, but not necessarily those of other motorized vehicle users.

A facility's capacity to serve the motorized vehicle mode reflects the effects of all motorized vehicles using the facility, including trucks, recreational vehicles, motorcycles, and intercity buses. In contrast, LOS for the motorized vehicle mode reflects the perspective of automobile drivers, but not necessarily the perspectives of other motorized vehicle users. Although automobiles are usually the dominant motorized vehicle type on roadways, analysts should use care in interpreting LOS results in special cases, such as intermodal terminal access routes, where trucks may dominate.

Pedestrian and Bicycle Modes

Pathways parallel to freeways and multilane highways are analyzed by using the off-street facility procedures.

Depending on local regulations, pedestrians and bicyclists may be allowed on all types of uninterrupted-flow facilities, including sections of freeways. However, research is only available to support LOS estimation methods for bicyclists traveling on two-lane and multilane highways. Pathways that are parallel to freeways and multilane highways use the service measures for off-street pedestrian and bicycle facilities. Of the various types of interrupted-flow system elements, pedestrian and bicycle service measures are provided for urban street facilities, urban street segments, signalized intersections, and off-street pedestrian and bicycle facilities. Pedestrian LOS can also be calculated for two-way STOP-controlled intersections and roundabouts.

Transit Mode

Bus service on uninterrupted-flow facilities typically serves longer-distance trips, with few (if any) stops. The *Transit Capacity and Quality of Service Manual* (TCQSM) (*8*) provides performance measures that can be used to evaluate bus service along uninterrupted-flow facilities as well as rail service operating within an uninterrupted-flow facility's right-of-way.

Transit service measures are provided only for transit service operating in mixed traffic or in exclusive lanes on urban streets. Consult the TCQSM for performance measures for other situations.

The HCM provides transit service measures for urban street facilities and segments to facilitate multimodal comparisons of urban street LOS. The TCQSM provides identical service measures for these system elements. The TCQSM provides additional performance measures for evaluating transit operations. Some of the HCM's performance measures, such as delay, may also be useful in multimodal comparisons—for example, in evaluating changes in person delay at an intersection as a result of a project being considered.

Freeway and Multilane Highway Service Measures

Motorized Vehicle Mode

Density is the motorized vehicle service measure for all freeway and multilane highway system elements.

Although travel speed is a major concern of drivers that relates to service quality, freedom to maneuver within the traffic stream and proximity to other vehicles are equally noticeable concerns. These qualities are related to the *density* of the traffic stream. Unlike speed, density increases as flow increases up to capacity, resulting in a service measure that is both perceivable by motorists and sensitive to a broad range of flows. Density is used as the service measure for freeway facilities, basic freeway segments, ramp junctions, weaving segments, and multilane highways.

Bicycle Mode

Bicycle LOS for multilane highways is based on a *bicycle LOS score* model. The model uses variables determined from research relating to bicyclists' comfort and perceived exposure while riding on multilane highways, such as separation from traffic, motorized traffic volumes and speeds, heavy-vehicle percentage, pavement quality, and (if present) on-highway parking.

Higher vehicle volumes, a greater proportion of trucks and buses, and higher vehicle speeds all act to decrease a bicyclist's perceived comfort and traffic exposure. Striped bicycle lanes or roadway shoulders add to the perceived sense of traffic separation and improve the LOS. Pavement quality affects bicyclists' ride comfort: the better the pavement quality, the better the LOS.

Two-Lane-Highway Service Measures

Motorized Vehicle Mode

Traffic operations on two-lane, two-way highways differ from those on other uninterrupted-flow facilities. Lane changing and passing are possible only in the face of oncoming traffic. In any given direction, passing demand increases as flows increase. Passing capacity decreases as opposing flows increase. Therefore, on two-lane highways, unlike other types of uninterrupted-flow facilities, traffic flow in one direction influences flow in the other direction. Motorists must adjust their travel speeds as volume increases and the ability to pass declines.

Traveler expectations for and travel conditions on two-lane highways are different from those for other uninterrupted-flow facilities.

Efficient mobility is the principal function of major two-lane highways that connect major traffic generators or that serve as primary links in state and national highway networks. These routes tend to serve long-distance commercial and recreational travelers, and long sections may pass through rural areas without traffic control interruptions. Consistent high-speed operations and infrequent passing delays are desirable for these facilities.

Other paved two-lane rural highways are intended to serve primarily an accessibility function. Although high speed is beneficial, it is not the principal concern. Delay—as indicated by the formation of platoons—is more relevant as a measure of service quality.

Two-lane roads also serve scenic and recreational areas where the vista and environment are meant to be experienced and enjoyed without traffic interruption or delay. A safe roadway is desired, but high-speed operation is neither expected nor desired. For these reasons, three service measures are used for two-lane highways: *percent time-spent-following, average travel speed,* and *percent of free-flow speed.*

Percent time-spent-following reflects the freedom to maneuver. It is the average percentage of travel time that vehicles must travel in platoons behind slower vehicles because of the inability to pass.

Percent time-spent-following defined.

Average travel speed reflects mobility on a two-lane highway: it is the length of a highway segment divided by the average travel time of all vehicles traversing the segment in a given direction during a designated interval.

Average travel speed defined.

Percent of free-flow speed reflects the ability of vehicles to travel at or near the posted speed limit.

Percent of free-flow speed defined.

LOS criteria use one or two of these measures. On major two-lane highways, for which efficient mobility is paramount, both percent time-spent-following and average travel speed define LOS. However, roadway alignments with reduced design speeds will limit the LOS that can be achieved. On highways for which accessibility is paramount and mobility less critical, LOS is defined only in terms of percent time-spent-following, without consideration of average travel speed. On two-lane highways in developed rural areas, LOS is defined in terms of percent of free-flow speed.

Bicycle Mode

Bicycle LOS for two-lane highways is determined by a *bicycle LOS score* model in the same manner as described above for multilane highways.

Urban Street Facility and Segment Service Measures

Motorized Vehicle Mode

The service measure for the motorized vehicle mode on an urban street is through-vehicle travel speed. Motorists traveling along arterial streets expect to be able to travel at or near the posted speed limit between intersections and to have to stop only infrequently. As delay due to traffic control devices and to other roadway users (e.g., vehicles stopped in a travel lane waiting to turn, buses stopping to serve passengers, or pedestrian crossings) increases, the lower the average speed and the lower the perceived LOS.

Chapter 18 presents an alternative performance measure well suited for determining multimodal LOS trade-offs and designing complete streets.

Research on automobile travelers' perceptions of LOS, as part of the National Cooperative Highway Research Program (NCHRP) 03-70 project, revealed that a combination of stops per mile and left-turn lane presence at signalized intersections had the highest statistical significance. However, the HCQS Committee elected to retain usage of a time-based service measure to analyze motorized vehicle LOS on urban streets for this edition of the HCM. The alternative NCHRP 03-70 methodology is also presented in Chapter 18, Urban Street Segments, since it is well suited for applications with a focus on determining multimodal LOS trade-offs and designing complete streets.

Pedestrian Mode

Urban street pedestrian LOS combines the quality of walking along a street, crossing at signalized intersections, and crossing the street between traffic signals.

Pedestrian LOS for urban streets is based on a *pedestrian LOS score* model that includes variables determined from research on pedestrians' perceptions of LOS. These variables relate to pedestrians' experiences walking along street links between signalized intersections, crossing side streets at signalized intersections, and crossing the street between signalized intersections.

The link component relates both to the density of pedestrians along the street and to pedestrian comfort and perceived exposure to traffic. The pedestrian density indicator is a function of pedestrian volumes and sidewalk width, while the nondensity indicator is a function of separation from traffic due to distance and physical objects, sidewalk presence and width, and motorized traffic volumes and speeds. The worse of the two indicators is used to determine pedestrian-perceived link LOS. The nondensity indicator more commonly determines LOS, but density can control in locations used by high volumes of pedestrians.

The signalized intersection component relates to pedestrian delay and perceived exposure to or interaction with traffic. The exposure elements of the indicator include potentially conflicting traffic volumes, parallel traffic volumes, parallel traffic speed, crossing width, and channelizing-island presence.

The roadway-crossing component is a function of the lesser of the delay in waiting for a gap to cross the street and the delay involved in diverting to the nearest signalized intersection. It also incorporates the link and signalized intersection components, which relate to the quality of the pedestrian environment experienced when pedestrians divert to a signal, either because of lower delay or a prohibition on crossings between signalized intersections.

Overall, pedestrian LOS is improved by the provision of sidewalks, wider sidewalks, a greater degree of separation from traffic, and reduced delays crossing the street at both signalized and unsignalized locations. Higher traffic volumes, higher traffic speeds, and wider streets tend to reduce pedestrian LOS.

Bicycle Mode

Urban street bicycle LOS combines the quality of bicycling along the street between traffic signals and the quality of passing through signalized intersections.

Bicycle LOS for urban streets is based on a *bicycle LOS score* model that includes variables determined from research on bicycle riders' perceptions of LOS. These variables relate to bicyclists' experiences at signalized intersections and their experiences on street links between signalized intersections. The intersection component relates to bicyclist comfort and perceived exposure to traffic and is a function of separation from traffic, cross-street width, and motorized traffic volumes. The link component similarly relates to comfort and perceived exposure. It is a function of separation from traffic, motorized traffic volumes, traffic speeds, heavy-vehicle percentage, presence of parking, pavement quality, and the frequency of unsignalized intersections and driveways between traffic signals.

Higher vehicle volumes, a greater proportion of trucks and buses, higher vehicle speeds, and presence of parking all decrease a bicyclist's perceived comfort. Striped bicycle lanes or roadway shoulders add to the perceived sense of traffic separation and improve the LOS. Pavement quality affects bicyclists' ride comfort: the better the pavement quality, the better the LOS.

Transit Mode

The transit service measure applies to bus, streetcar, and at-grade light rail services that make stops along an urban street.

The service measure combines traveler perceptions of walking to a transit stop, waiting for a transit vehicle, and riding on the vehicle.

Transit LOS for urban streets is based on a *transit LOS score* model that includes variables determined from research on transit riders' perceptions of LOS. The variables relate to passengers' experiences walking to a transit stop on the street, waiting for the transit vehicle, and riding on the transit vehicle. The walking-to-the-stop component is based on the street's pedestrian LOS score: transit passengers are usually pedestrians before and after their transit trip—and improvements to the pedestrian environment along streets with transit service contribute to a better LOS. The waiting component is a function of the transit vehicle frequency (relating to wait time and trip-making convenience), service reliability (unplanned passenger waiting time at the stop), and the presence of shelters and benches (which make waiting time more comfortable). Finally, the riding-on-the-vehicle satisfaction is a function of average travel speed (a convenience factor) and passenger loads (a comfort factor).

Urban Street Intersections

Motorized Vehicle Mode

Control delay is the motorized vehicle service measure for urban street intersections.

The service measure for the motorized vehicle mode at all urban street intersections—including signalized intersections, all-way STOP-controlled intersections, two-way STOP-controlled intersections, roundabouts, and interchange ramp terminals—is *control delay*.

Control delay, which was defined in Chapter 4, Traffic Operations and Capacity Concepts, is a measure of driver discomfort, frustration, fuel consumption, and increased travel time. Different variables are used to measure control delay, depending on whether the intersection is signalized or unsignalized. As control delay increases, LOS worsens. The maximum control delay allowed for a given LOS at unsignalized intersections is lower than for signalized intersections because of differing driver expectations. Drivers are willing to tolerate longer delays at signal-controlled intersections because they know their delay will be finite.

Pedestrian, Bicycle, and Transit Modes

At the time of publication, research was insufficient to provide pedestrian and bicycle LOS for urban street intersections, except for signalized intersections and—for pedestrians only—two-way STOP-controlled intersections. The HCM provides transit LOS measures only at the urban street segment and facility levels.

Signalized Intersections

Pedestrian LOS at signalized intersections is based on a *pedestrian LOS score* model that incorporates conflicting motorized vehicle volumes and speeds, crosswalk length, average pedestrian delay, and the presence of right-turn channelizing islands. Pedestrian LOS improves with lower motorized vehicle volumes and speeds, shorter crosswalk lengths, lower delay, and the provision of right-turn channelizing islands.

Bicycle LOS at signalized intersections is based on a *bicycle LOS score* model that incorporates perceived separation from motorized vehicle traffic, motorized vehicle volumes, cross-street width, and presence and utilization of on-street parking. Bicycle LOS improves with greater perceived separation from motorized vehicle traffic, lower motorized vehicle volumes, shorter cross-street widths, and reduced on-street parking conflicts.

Two-Way STOP-Controlled Intersections

Pedestrian LOS at two-way STOP-controlled intersections is based on average pedestrian *control delay* crossing the major street. Lower vehicle volumes, presence of a median, and provision of pedestrian crossing treatments that improve motorist yielding rates all help to improve pedestrian LOS.

Off-Street Pedestrian and Bicycle Facilities

Pedestrian Mode

The service measure for off-street exclusive pedestrian facilities is pedestrian space.

Off-street facilities used exclusively by pedestrians (e.g., pedestrian pathways, plazas, and stairways) use *pedestrian space* as the service measure. As the space available to pedestrians increases, their ability to move at their desired speed along their desired line of travel increases. Therefore, as the space available to a pedestrian on an off-street facility increases, the LOS improves.

The pedestrian service measure for shared off-street facilities is the number of times per hour a pedestrian meets or is passed by bicyclists.

When an off-street facility is shared by pedestrians and bicyclists, pedestrian quality of service is much more affected by the bicyclists using the facility than by other pedestrians because of the speed differential between the two types of travelers. Therefore, the pedestrian service measure for shared off-street facilities is based on *events,* the number of times per hour that a pedestrian is met by or passed by bicyclists. The greater the number of bicyclists on a shared facility, the lower the pedestrian LOS.

Bicycle Mode

The bicycle service measure for all off-street facilities is a bicycle LOS score.

Bicycle LOS for off-street bicycle facilities, both exclusive and shared, is based on a *bicycle LOS score* model that includes variables determined from research on bicycle riders' perceptions of LOS. These variables consist of the number of times a bicyclist meets other path users per minute, the number of times per minute on average that a bicyclist passes or is delayed in passing other path users, the presence of a centerline, and the path width. As the number of other path users (including bicyclists) increases, the LOS declines. Wider paths and the absence of a centerline contribute to better LOS.

5. REFERENCES

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

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