Tools for Evaluating Level & Quality of Service for All Modes: A Literature Review

Hillsborough County, Florida

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GLOSSARY

BEQI – Bicycle Environmental Quality Index

BLOS – Bicycle Level of Service

BNA – Bicycle Network Analysis

CDOT – Charlotte Department of Transportation

FDOT – Florida Department of Transportation

FHWA – Federal Highway Administration

HART – Hillsborough Area Regional Transit Authority

HCM – Highway Capacity Manual

HMPO – Hillsborough Metropolitan Planning Organization

LOS – Level of Service

LTS – Level of Traffic Stress

MMLOS – Multimodal Level of Service

NACTO – National Association of City Transportation Officials

OSM – OpenStreetMap

PEQI – Pedestrian Environmental Quality Index

PLOS – Pedestrian Level of Service

Q/LOS – Quality/Level of Service

SANDAG - San Diego Association of Governments

TCQSM – Transit Capacity and Quality of Service Manual

TLOS – Transit Level of Service

USDG – Urban Street Design Guide

VMT – Vehicle Miles Traveled

INTRODUCTION

The Hillsborough Metropolitan Planning Organization (HMPO) in Hillsborough County, Florida initiated this white paper with the objectives of (1) reviewing HMPO's current multimodal level of service (MMLOS) methodology and (2) conducting a review of best practices in applying MMLOS calculations and criteria. This white paper is composed of four parts: (1) a summary of HMPO's current methodology and how it is applied, (2) a literature review on best practices, (3) a summary of interviews conducted with subject matter experts, and (4) a review of the challenges and opportunities of the various methodologies explored in the paper.

EXISTING METHODOLOGY

Background

HMPO currently uses a multimodal transportation database to store countywide highway performance data. The database is linked to the HMPO's mapping system via linear referencing. In 2012, HMPO began incorporating MMLOS data into the database, using data collected from previous MMLOS studies. The purpose of this effort was to create a single-source database that could be updated and used for future countywide MMLOS calculations.

Three methodologies for calculating MMLOS were explored at the time:

1. *HMPO's MMLOS Microsoft Excel Spreadsheets* — This was the most comprehensive of the three methods and relied on the widest set of roadway attributes, above those required by the Florida Department of Transportation (FDOT). The spreadsheets were developed over time and were used for various bicycle and pedestrian studies. The level of detail included in the spreadsheets varied because individual study requirements, including data collection efforts, were not consistent. The HMPO wanted to compare the level of detail required for the spreadsheets, relative to the data required for FDOT's Q/LOS and ARTPLAN analysis, described next.
2. The Florida Department of Transportation's (FDOT) *2009 Highway Quality Level of Service (Q/LOS) Manual* — This was the most simplified methodology explored and relied on lookup tables and performance attributes found in the Q/LOS Handbook. The Handbook provides level of service (LOS) measures, thresholds, and estimation methodologies for the auto, transit, bicycle, and pedestrian modes. It was designed for use in generalized planning and conceptual planning, and refers users to *Highway Capacity Manual* (HCM) methodologies when more detailed operational analysis is required. The auto LOS is not comparable with the bicycle LOS (BLOS) and pedestrian LOS (PLOS) scales because they are based on different dimensions of perceived and measured traveler satisfaction.
3. *FDOT's ARTPLAN* — The ARTPLAN software is a part of the LOSPLAN 2009 software package which is produced by the University of Florida for FDOT. HMPO's spreadsheet formulations and the 2009 ARTPLAN software have very similar origins in their MMLOS calculations, but the ARTPLAN software uses more generic assumptions for some of the calculation data items and

highway attributes. The software allows inputs to be entered on a corridor basis and reports the three MMLOS values for a corridor or its subsections.

HMPO decided that the data collection required for calculating MMLOS using the FDOT ARTPLAN software was sufficient for its needs. Therefore, the database was designed to be able to collect, update, and maintain the data necessary to conduct the ARTPLAN analysis for BLOS and PLOS.

Transit LOS (TLOS) differs from BLOS and PLOS calculations in that it relies mainly on transit service levels and not on highway characteristics. HMPO uses a version of the TLOS calculation that is based on roadway corridors with frequent routes and long spans of service. The TLOS values are based on the individual route frequencies and not the total number of routes on a given roadway segment. The operating characteristics come from the Hillsborough Area Regional Transit Authority (HART) in a spreadsheet format that documents the latest routes and operating attributes. This approach is different from the ARTPLAN methodology, which uses the combined number of transit trips on the road segment based on the frequency and hours of transit service of all routes on the segment. HMPO decided to use its route-based method and not the ARTPLAN segment-based methodology. However, new structures for the ARTPLAN TLOS method were provided for future development if HMPO ever decided that the ARTPLAN method should be used.

Current Analysis Procedures

Bicycle Level of Service (BLOS)

The BLOS model in ARTPLAN uses five variables:

- Average effective width of the outside through lane,
- Motorized vehicle volumes,
- Motorized vehicle speeds,
- Heavy vehicle (truck) volumes, and
- Pavement condition.

Average effective width is largely determined by the width of the outside travel lane and striping for bicyclists, but also includes other factors such as the effects of on-street parking and drainage grates. Each of the variables is weighted by coefficients derived from a stepwise regression, modeling each factor’s importance. A numerical LOS score is determined and stratified to a LOS letter result. While the determination of automobile LOS in the HCM is typically based on one service measure (e.g., average travel speed), BLOS is based on multiple factors.

Pedestrian Level of Service (PLOS)

The PLOS model in ARTPLAN uses four variables:

- Existence of a sidewalk,

- Lateral separation of pedestrians from motorized vehicles,
- Motorized vehicle volumes, and
- Motorized vehicle speeds.

Each of the variables is weighted by its relative importance, determined from a regression model. A numerical LOS score is determined along with the corresponding LOS letter. Thus, like the bicycle LOS approach (but unlike the automobile approach), PLOS is determined based on multiple factors.

Transit Level of Service (TLOS)

TLOS uses the *Transit Capacity and Quality of Service Manual* (TCQSM), 2nd edition's table for urban scheduled transit service based on adjusted service frequency. The adjusted service frequency is a weighted average of bus frequency along a facility, accounting for routes that may only serve a portion of the facility. The adjusted service frequency is converted to an average headway and assigned a letter (A–F).

Assessment of Current Methodology

The current methodology allows for project-level comparisons across multiple modes. It allows engineers and planners to evaluate the effects of different roadway cross-sections and intersection configurations across various modes and user groups. The methodology is data-intensive; however, the ARTPLAN software provides an easy-to-use format for calculating vehicular and multimodal LOS.

HMPO's primary concern with the existing methodology is that is does not reflect the current perception of multimodal users. For example, the current methodology would assign a letter grade "C" to a roadway with a five-foot paved shoulder, indicating an acceptable LOS, regardless of the number of travel lanes, vehicle volumes, or vehicle speeds. However, a recent study conducted by FDOT District 5 showed that with the presence of a conventional on-street bike lane, more than 80% of bicyclists observed still chose to ride on the sidewalk. This result suggests a mismatch with the way multimodal quality of service is being evaluated and the way the users of the roadway system prefer to travel.

The current methodology is limited in its application. It focuses on segment LOS, or travel parallel to motorized vehicle traffic, and does not take into account intersection conditions. It also does not account for innovations in multimodal infrastructure. The City of Tampa has worked diligently to implement the City's first cycle track on Cass Street downtown and has striped green bicycle lanes in spot locations. The added benefit to users provided by these treatments cannot be captured by the current methodology.

LITERATURE REVIEW

A literature review of a range of methodologies that evaluate LOS and other performance metrics for non-automobile modes was completed to develop a baseline understanding of best practices. A summary of the documents reviewed, the authors, and the key takeaways from each of the documents is provided in **Table 1**.

Table 1: Summary of Documents Reviewed for Literature Review

Document	Date	Authors/Institute	Key Takeaways

The Highway Capacity Manual's Method for Calculating Bicycle and Pedestrian Levels of Service: the Ultimate White Paper
 	
https://www.lewis.ucla.edu/wp-content/uploads/sites/2/2014/09/HCM-BICYCLE-AND-PEDESTRIAN-LEVEL-OF-SERVICE-THE-ULTIMATE-WHITE-PAPER.pdf
	2014	University of California, Los Angeles - Lewis Center for Regional Policy Studies and Institute of Transportation Studies
		
		Herbie Hu and Robin Liggett
			• Reviews the BLOS and PLOS components of MMLOS.
			• The HCM models are based on studies of participants in Florida and with limited testing outside of Florida.
			• The HCM models were constructed based on variables known to influence walking and bicycle at the time and do not account for the full range of variables and innovation currently of interest to planners.
			• Review of PLOS:
			  ○ *Intersection score* – number of lanes crossed as greatest contribution, followed by vehicle speed and volume; less sensitive to pedestrian delay and refuge islands
			  ○ *Link score* – width of walking area, separation from vehicles, and vehicle volumes play largest role; insensitive to sidewalk quality, lighting, and sidewalk width beyond 10’
			• Review of BLOS:
			  ○ *Intersection score* – function of roadway width and type of bicycle facility; insensitive to innovative treatments (i.e. bike boxes)
			  ○ *Link score* – influenced by vehicle volumes (particularly trucks), vehicle speeds, and type of bicycle facility; insensitive to innovative treatments (i.e., green paint) and bicycle crowding
			• It is possible to validate PLOS and BLOS and include sensitivity to innovative treatments. The authors argue this effort would be resource-intensive and there may be other metrics and policies that have replaced the need for such a detailed evaluation.

Document	Date	Authors/Institute	Key Takeaways

NCHRP 616: Multimodal Level of Service Analysis for Urban Streets
 	
http://www.trb.org/Publications/Blurbs/160228.aspx
	2008	Transportation Research Board
		
		Richard Dowling, David Reinke, Aimee Flannery, Paul Ryus, Mark Vandehey, Theo Petritsch, Bruce Landis, Nagui Rouphail, and James Bonneson
			• Used video labs in four metropolitan areas to have participants rate their satisfaction with the driving, walking, and bicycling conditions shown in the videos. Developed regression models to predict participants' average rating based on the conditions the participants observed (e.g., traffic volumes, facility characteristics)
			• Video lab approach was not applicable for transit; instead, documented relationships between ridership and service quality were used primarily to develop the transit model
			• The models were tested for reasonableness and refined through a series of workshops/field tests with local, regional, and state transportation agency staff in 10 metropolitan areas across the U.S.
			• Models predict LOS for the automobile, transit, bicycle, and pedestrian modes on urban arterials and collectors.
			  ○ Auto – Uses stops per mile and average speed as the primary variables
			  ○ Transit – Primary variables are bus headways, perceived travel time, and the pedestrian LOS score
			  ○ Bicycle – Weighted combination of the cyclist's experience at intersections and on street segments
			  ○ Pedestrian – Function of segment and intersection level of service and mid-block crossing difficulty
			• Addresses nine limitations of the HCM 2000 methodology.
			• The uniform definition of LOS used in the models provides a consistent basis for comparing levels of service across modes.
			• Research led to the bicycle, pedestrian, transit, and automobile perception methods in the HCM 2010.

TCRP Report 165: Transit Capacity and Quality of Service Manual (Third Edition)	2013	Transportation Research Board Paul Ryus, Alan Danaher, Mark Walker, Foster Nichols, William Carter, Elizabeth Ellis, Linda Cherrington and Anthony Bruzzone	• A reference document that provides research-based guidance on transit capacity and quality of service issues. • The Quality of Service Concepts chapter reviews factors that have been demonstrated to influence transit passengers' perceptions of transit service quality. • The Quality of Service Methods chapter presents computational methods for evaluating transit availability (frequency, hours of service, service coverage) and comfort and convenience (on-board crowding, reliability, relative transit/auto travel times). • Mode-specific chapters present methods for evaluating transit operations. For example, the bus methodologies focus on bus capacity, speed, and reliability to evaluate bus performance.

Document	Date	Authors/Institute	Key Takeaways
			• A spreadsheet for forecasting bus speeds is available online. It requires a myriad of input data, including: ◦ Average dwell time (can be input directly or estimated based on passenger volumes, fare collection method[s], and bus characteristics) ◦ Coefficient of variation of dwell times ◦ Design failure rate (percent of time a bus arrives to find all stopping positions already occupied) ◦ Average green-to-cycle length ratio of the downstream signal (if present) ◦ Traffic signal cycle length ◦ Bus stopping position (in/out of the travel lane) ◦ Bus stop location (near-side, far-side, mid-block influenced by nearby signals, mid-block not influenced by nearby signals) ◦ Number of loading areas (number of buses that can stop simultaneously) ◦ Area type (e.g., metro CBD) ◦ Curb lane volume ◦ Right-turn volume ◦ Pedestrian volume conflicting with right turns ◦ Scheduled buses per hour ◦ Average bus stop spacing ◦ Number of traffic signals relative to number of bus stops (more/same or fewer) ◦ Bus facility type (e.g., mixed traffic, bus lane with right turns allowed) ◦ Maximum bus running speed between stops (typically the speed limit) ◦ Skip-stop operation (yes/no), plus data on the stopping pattern if "yes" • The primary challenge of the TCQSM is deciding which of its performance measures and methods are most applicable to a given analysis.
MTI Report 11-19: Low-Stress Bicycling and Network Connectivity http://transweb.sjsu.edu/PDFs/research/1005-low-stress-bicycling-network-connectivity.pdf	2012	Mineta Transportation Institute, San Jose State University Maaza C. Mekuria, Ph.D., PE, PTOE, Peter G. Furth, Ph.D., and Hilary Nixon, Ph.D.	• Reviews the LTS criteria developed to measure low stress connectivity for the bicycle network. • Previous research supports that Americans have varying levels of tolerance for traffic stress—a combination of perceived dangers and stressors such as noise and exhaust fumes—associated with riding a bike in the roadway. While a small portion of the population is comfortable riding in mixed traffic, most people are "traffic-intolerant." • In order for the widest possible segment of the population to be attracted to bicycling, the most fundamental condition is a low-stress trip with minimal detour between their

Document	Date	Authors/Institute	Key Takeaways

			origin and destination.
			• LTS is rated from “LTS 1,” which is a level that most children can tolerate, to “LTS 4,” which is a level that may only be tolerable by strong and fearless cyclist in rare cases. A more detailed summary of LTS 1 through 4 conditions is provided below:
			  ○ LTS 1 – This condition presents little traffic stress and demands little attention from bicyclist. Bicyclists are either physically separated from traffic, have a dedicated space next to slow-moving traffic, or operate in mixed traffic where speed differentials are minimal. Intersections are easy to approach and cross.
			  ○ LTS 2 – This condition presents little traffic stress. While comfortable for most adults, it requires a little more attention than expected from children. This condition can include separated bike facilities, bike lanes with adequate clearance from the travel lane and parking lane, and mixed traffic with low speed differentials.
			  ○ LTS 3 – This condition has higher traffic stress than LTS 2 (i.e., higher traffic speeds and volumes), but is substantially less than a multilane roadway. This condition can also include bike lanes that are next to moderate-speed traffic.
			  ○ LTS 4 – A condition that is typically experienced in mixed traffic on multilane roadways. LTS 4 includes all level of traffic stress above LTS 3.
			• Components that affect the LTS score are largely based on traffic speed, traffic volume, number of travel lanes, the presence of parking, and whether a separated bike lane is present.
			• Traffic stress for segments is determined based on 3 classes of bikeways: separated bikeways, bike lanes, and mixed traffic:
			  ○ Physically separated bike lanes are LTS 1. These include cycle tracks, shared use paths, trails, and other bicycle-only facilities separated from traffic. LTS 1 does not include sidewalks unless they have been designated for bicycle use.
			  ○ A bike lane’s LTS varies based on street width, bike lane width, traffic speed, and bike lane blockage. The metric with the lowest LTS ranking governs the link’s LTS.
			  ○ Sometimes it is known that a bike lane or cycle track is blocked on a regular basis due to loading activities, double parking, etc. In these cases, the segment is LTS 3.
			  ○ The greatest factors influencing LTS in mixed-traffic operations are the number of travel lanes and the speed limit or observed speeds. Streets that are under 3 lanes and have a speed limit of 25 mph are LTS 1 (if the streets do not have a marked center line or are classified as residential) or LTS 2.
			• Similar to the segment analysis, intersection approaches can be scored based on the right turn condition (with or without a pocket bike lane) and the crossing condition (based on

Document	Date	Authors/Institute	Key Takeaways
			traffic speed, the number of travel lanes, and whether the intersection is signalized with the presence of a median) • Previous research in Vancouver, B.C. found that 75 percent of bicycle trips were within 10 percent of the shortest trip distance and 90 percent of bicycle trips were within 25 percent of the shortest trip. This finding indicates that many bicyclists are willing accept up to a 25 percent detour to have a low-stress experience. • The LTS methodology also allows practitioners to evaluate overall network connectivity. • The paper also explores measures for connectivity and, specifically, the fraction of trips that can be made by bicycle without exceeding a given level of traffic stress or requiring an excessive detour.
peopleforbikes, Bicycle Network Analysis https://bna.peopleforbikes.org/#/methodology	2017	peopleforbikes	• The Bicycle Network Analysis (BNA) Score is a methodology recently developed by peopleforbikes as a way to measure how well the existing bicycle network connects people with places they want to go. • The methodology combines a simplified Level of Traffic Stress (LTS) analysis with US Census data to understand how the low-stress network connects residents, jobs, and community. • In the simplified LTS analysis, the methodology distills streets down to “low” or “high” stress based on bicycle facility type (cycle track, buffered bike lane, bike lane, shared traffic), the number of travel lanes, speed and street width. • Census blocks receive a score out of 100 based on their connectivity to streets determined to be “low” stress, normalized by the population in that census block. • The spreadsheet tool developed to complete these calculations is publically available. • Peopleforbikes has also created an online mapping tool that has mapped this information and calculated the BNA score for most cities.

Document	Date	Authors/Institute	Key Takeaways

Network Connectivity for Low-Stress Bicycling
 	
http://www1.coe.neu.edu/~pfurth/Furth%20papers/2013%20Network%20Connectivity%20for%20Low%20Stress%20Bicycling%20(Furth,%20Mekuria)%20TRB%20compendium.pdf
	2013	TRB Annual Meeting, 2013
		
		Peter G. Furth, Ph.D. and Maaza C. Mekuria, Ph.D., PE, PTOE
			• A research white paper on the LTS methodology, developed to measure the level of traffic stress perceived by most riders based on traffic speed and number of travel lanes.
			• The LTS methodology is more meaningful to planners and citizens because Bicycle Level of Service models and the Bicycle Compatibility Index are “black boxes” in the sense that developing a classification requires complex calculations.
			• The LTS calculation is determined based on characteristics such as traffic speed, number of travel lanes, bike lane width, and parking lane presence through various tables. These tables provide an LTS rating, based on the characteristics. The LTS for a given intersection, approach, and/or segment is governed by the worst (highest) LTS rating in the tables. For instance, if a segment is determined to be LTS 3 based on one characteristic, but is LTS 1 or 2 based on another characteristic, the segment rating is LTS 3.
			• Bicyclists are willing to accept up to a 25 percent detour for longer trips, and up to a 33 percent detour for shorter trips, to have a less stressful experience.
			• Many networks develop “low stress islands,” where barriers break up segments of the network that are otherwise considered low stress. There are three main kinds of barriers:
			  ○ Linear features that require grade-separated crossings, such as freeways, railroads, and creeks.
			  ○ Multilane, high-speed arterial streets.
			  ○ Breaks in the street grid, such as cul-de-sacs.
			• A measure of connectivity is important to assess how well the network serves most of the population. Connectivity can be measured by taking the number of trips between an origin and destination that can be made by bicycle at a given LTS (for instance, LTS 2), with limited detours, and dividing the result by the total number of trips. The answer provides the fraction of trips that can be made by bicycle.
			• A case study at San Jose State University demonstrated how the areas accessible via low-stress trips can be mapped. Mapping connectivity allows planners to identify key corridors and connections where improvements can unlock low-stress islands.

Document	Date	Authors/Institute	Key Takeaways
Exploration and Implications of Multimodal Street Performance Metrics: What's a Passing Grade? http://www.lewis.ucla.edu/wp-content/uploads/sites/2/2014/09/EXPLORATION-AND-IMPLICATIONS-OF-MULTIMODAL-STREET-PERFORMANCE-METRICS.pdf	2014	University of California Transportation Center Madeline Brozen, Herbie Huff, Robin Liggett, Rui Wang, and Michael Smart	• Reviewed four multimodal methodologies: Fort Collins, San Francisco Bicycle Environmental Quality Index (BEQI) and Pedestrian Environmental Quality Index (PEQI), Charlotte BLOS/PLOS, and HCM 2010 MMLOS • The Fort Collins methodology assumes infrastructure is built to city-specific design criteria and is therefore difficult to apply elsewhere. • Charlotte and San Francisco place more emphasis on safety and less on walkability. • The HCM 2010 and BEQI/PEQI measures appeal to a more universal approach, where Charlotte BLOS/PLOS is more location-specific. • Authors argue a single-grade letter score depicts misleading views of bicycle and pedestrian experiences. The letter does not always correspond to users' experience on the street and limits the public's ability to engage in discussion about roadway performance. • If an agency's goal is to improve traveler satisfaction across all modes, HCM 2010 would be the best choice. • Improved safety or geometric design would be better evaluated through the Charlotte BLOS/PLOS. • BEQI/PEQI and Charlotte LOS are relatively easy tools to use for calculating current and potential LOS. • HCM is the most difficult tool to use and has little ability to account for small infrastructure improvements.

SUMMARY OF INTERVIEWS

To provide depth to the literature review, interviews were conducted with subject matter experts from two cities, the City of Charlotte and the San Diego Association of Governments (SANDAG), as well as from the Federal Highway Administration (FHWA). A summary of the themes identified through the interviews is outlined in **Table 2**, below. The detailed interview notes can be found in Appendix A.

Table 2: Subject Matter Expert Interview Summary

Agency	Person(s) Interviewed, Position	Themes
Charlotte Department of Transportation Charlotte, NC	Scott Curry, Pedestrian Coordinator Tracy Newsome, Ph.D. Transportation Planner	• The City developed the P/BLOS methodology to evaluate how intersections were serving pedestrians and bicycles. • The methodology has been applied to every signalized intersection in the City and the City has a database of the LOS for all intersections. • P/BLOS is used, along with congestion and safety measures, to inform small-area planning efforts and to identify priority intersection locations for improvements. • The City developed and adopted the Urban Street Design Guide (USDG). This provides specific street design guidance based on the "place" of the street.
SANDAG San Diego, CA	Mike Calandra, Senior Transportation Modeler	• SANDAG uses an activity-based model to evaluate changes in mode split resulting from various changes to auto, transit, and bicycle infrastructure. • They've found that adding/removing bicycle links has a greater impact on mode choice than changing the type of bicycle facility. • They do not yet have the ability to evaluate pedestrian infrastructure and cannot assign bicycle and pedestrian trips at the link level. • SANDAG reports vehicle miles traveled (VMT) for every project and can track VMT by origin and destination pairs. • Adding active transportation links in the model is a way to mitigate VMT. The model can evaluate the varied effects of bicycle infrastructure in urban and rural contexts.

Agency	Person(s) Interviewed, Position	Themes
FHWA National	Dan Goodman, Office of Human Environment Livability Team	• When evaluating trade-offs between modes, there will always be a comparison to traditional LOS. It is important to understand the limitations of LOS and have a more holistic understanding of everything that goes into the planning process. • The P/BLOS components of MMLOS are helpful inputs. The BLOS methodology is not refined enough for today's condition and does not include recent innovations, such as cycle tracks. It can be hard to move the needle for P/BLOS. Widening the sidewalk, for example, shows little benefit in the analysis. • A new tool was recently created to limit the time and expense of performing system-wide LTS analysis.

METHODOLOGIES

This section summarizes the findings from the literature review of each methodology. Each sub-section below outlines the methodology, provides example applications, and identifies the data requirements for applying the methodology as well as the challenges and opportunities within those applications.

Multimodal Level of Service (MMLOS)

Overview

The 2010 Highway Capacity Manual (HCM) introduced MMLOS analysis for urban streets. The HCM MMLOS analysis provides a LOS model for each of the four modes (automobile, transit, bicycle, and pedestrian) for arterial and collector roadways. The LOS measures are based on traveler perceptions. The pedestrian, bicycle, and automobile equations were developed based on participant-rated conditions of over 90 typical segments. The transit model was based on traveler response data to changes in transit service quality. For example, when service frequency or travel time is improved, ridership increases. All four models incorporate multiple service quality factors as inputs, as opposed to relying solely on delay.

This paper focuses on the MMLOS procedures found in the 2010 HCM. The HCM 6th Edition: A Guide for Multimodal Mobility was updated to reflect the *Transit Capacity and Quality of Service Manual,* 3rd ed., and minor changes were made to BLOS and PLOS. The sources reviewed centered on the 2010 HCM and there has not yet been a comprehensive evaluation of the refinements made to MMLOS in the 6th Edition of the HCM.

Application

The MMLOS method defines the following terms:

- Intersection — Signal, roundabout, or stop-controlled
- Link — Portion of the street between two signalized intersections
- Segment — Combination of a link and its downstream signalized intersection
- Facility — Two or more consecutive segments

The pedestrian and bicycle modes can be evaluated at the intersection, link, segment, and facility level. Vehicular LOS can be evaluated at the intersection, segment, and facility level. The transit LOS model is limited to segment and facility operations. The LOS thresholds are the same for all modes. They were designed so the modal LOS scores can be directly compared to each other and to reflect similar average traveler satisfaction across modes. The HCM also provides LOS methods for off-street pedestrian and bicycle facilities, including walkways offset more than 35 feet from the street, pedestrian-only streets, stairways, and shared-use paths (HCM 2010).

Table 3 summarizes the key factors for each mode and their effect on LOS. A (+) indicates that a higher value for that variable positively impacts LOS. A (-) indicates that a higher value negatively impacts LOS.

Table 3: Key Factors of HCM MMLOS

Pedestrians	Bicyclists	Transit
Link LOS		**Segment LOS**
Outside travel lane width (+) Bicycle lane/shoulder width (+) Buffer presence (e.g., on-street parking, street trees) (+) Sidewalk presence and width (+) Volume and measured speed of vehicle traffic in outside travel lane (–)	Volume and measured speed of traffic in outside travel lane (–) Heavy vehicle percentage (–) Pavement condition (+) Bicycle lane presence (+) Bicycle lane, shoulder, and outside lane widths (+) On-street parking utilization (–)	Service frequency (+) Bus travel speed (+) Bus stop amenities (+) Pedestrian link LOS (+) Excess wait time due to late bus arrival (–) On-board crowding (–)
Intersection LOS		
Permitted left turn and right-turn-on-red volumes (–) Cross-street motor vehicle volumes and speeds (–) Crossing length (–) Average pedestrian delay (–) Right-turn channelizing island presence (+)	Width of lanes (+) Cross-street width (–) Motor vehicle traffic volume in the outside lane (–)	N/A

(+) Higher value has positive impact to LOS
(-) Higher value has negative impact to LOS

At the project level, practitioners can use the HCM MMLOS to evaluate the tradeoffs of various street designs in terms of their effects on the auto driver's, transit passenger's, bicyclist's, and pedestrian's perceptions of the quality of service provided by the street. The individual mode scores can be used to understand the degree to which an urban street meets the needs of all users and the effect various alternatives have on the level of service. This analysis can be conducted for an entire network of streets and used to prioritize transit, bicycle, and pedestrian improvements[1].

[1] Richard Dowling et al., *NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets*, Transportation Research Board, 2008.

Data Needs

Table 4 summarizes the data required, by mode, for the MMLOS evaluation. This evaluation is the most data-intensive of the methodologies considered, but agencies can rely on default values for many of the inputs to reduce the data requirements. NCHRP Report 825 provides guidance on when to use default values and gives suggested values. Relevant excerpts from the report are provided in Appendix B. Software, such as ARTPLAN, is also available to assist with data entry and computation.

Table 4: MMLOS Data Needs

Pedestrians	Bicyclists	Transit
	Segment LOS	
– Segment length – Vehicle speed – Vehicle flow rate – Number of through lanes – Width of outside through lane – Width of bicycle lane – Width of paved outside shoulder – Median type and curb presence – Pedestrian flow rate – Proportion of on-street parking occupied – Downstream intersection width – Presence of sidewalk – Total walkway width – Effective width of fixed objects – Buffer width – Spacing of objects in buffer – Distance to nearest signal-controlled crossing – Legality of midblock pedestrian crossing – Percent of sidewalk adjacent to window,	– Segment length – Vehicle speed – Vehicle flow rate – Number of through lanes – Width of outside through lane – Width of bicycle lane – Width of paved outside shoulder – Median type and curb presence – Percent heavy vehicles – Proportion of on-street parking occupied – Number of access points – Pavement condition – Bicycle delay – Bicycle LOS score for intersection	– Segment length – Vehicle speed – Excess wait time – Passenger trip length – Transit frequency – Passenger load factor – Area type (major metro area CBD or other) – Proportion of stops with shelters – Proportion of stops with benches – Pedestrian link LOS score –

Pedestrians	Bicyclists	Transit
building, or fence – Pedestrian delay – Pedestrian LOS score for intersection		
Intersection LOS		
All intersections: – Vehicle flow rate – Number of lanes – Number of right-turn islands – Pedestrian flow rate – Crosswalk length – Crosswalk width Signalized: – Total walkway width – Corner radius – Right-turn-on-red flow rate – Permitted left-turn flow rate – Midblock 85th percentile speed – Signal timing (walk, pedestrian clear, rest in walk, cycle length, yellow change, red clearance, duration of phase serving pedestrians) – Present of pedestrian signal heads Two-Way Stop Controlled: – Presence of raised median Rate at which motorists yield to pedestrians – Degree of pedestrian platooning	– Vehicle flow rate – Number of lanes – Width of outside through lane – Width of bicycle lane – Width of paved outside shoulder – Bicycle flow rate – Proportion of on-street parking occupied – Street width – Signal timing (cycle length, yellow change, red clearance, duration of phase serving bicyclists) *No methodology for two-way stop controlled intersections	N/A

Challenges

A key challenge to applying HCM MMLOS is that it is data intensive and can be difficult to use. Because of its wide use, however, there are existing software packages, such ARTPLAN, which can aid in the evaluation process.

MMLOS has limited ability to account for small infrastructure improvements[2].

The PLOS does not currently take into account presence of lighting, the condition of the sidewalk, and sidewalk widths greater than 10 feet.

At a link level, the HCM BLOS is most sensitive to heavy vehicle volumes, degree of separation from motorized vehicle traffic, and the presence of on-street parking. It is relatively insensitive to overall traffic volumes and speeds and does not directly incorporate the number of travel lanes, other than to determine the traffic volume in the lane closest to bicyclists. At a facility level, a large constant in the equation makes it difficult to achieve a letter grade above C for any facility.[3] This makes it difficult to use facility LOS to document improvements to bicycle service when upgrading an on-street facility to a separated facility. The constant in the facility equation and the size of the range for each LOS letter at the link level were modified in the *HCM 6th Edition* to address these concerns. BLOS does not take into account innovative bicycle treatments that were not widely used in the U.S. at the time of the research, such as bicycle boxes, colored paint, bicycle signals, and cycle tracks.

Opportunities

MMLOS incorporates operational characteristics to a greater degree than other methodologies explored. Some of the heaviest weighted variables in the MMLOS calculations include heavy vehicle (truck) volumes and percentage of on-street parking.[2]

Of the methods explored, HCM MMLOS is the best suited for comparisons across modes. The method was developed specifically to allow comparisons of different allocations of the street right-of-way between travel modes. The model can be adapted to and validated for local conditions to improve its validity and to calibrate the level of service scores to local experience and perception. This effort is resource and time intensive, but can address several of the challenges mentioned, such as including additional factors into the PLOS and recalibrating the bicycle score to reflect the current users' perceptions.

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[2]Madeline Brozen et al., "Exploration and Implications of Multimodal Street Performance Metrics: What's a Passing Grade?" University of California Transportation Center, 2014.

Transit Capacity & Quality of Service Manual

Overview

The TCQSM is a comprehensive reference work for public transit practitioners. The TCQSM differs from the other methodologies explored here because of its emphasis on defining and describing quality of service concepts, including summarizing research about which quality of service factors are most important to transit riders. This makes the TCQSM an essential resource to refer to when considering changes to evaluation methodologies, or when seeking solutions to capacity or quality of service challenges. The TCQSM describes best practices and methodologies for evaluating transit operations and quality of service.

Quality of service is perceived differently by different types of users. Transit passengers, transit agency staff, motorists, community members, and decision-makers all have differing opinions on the goals and roles of transit service. The TCQSM defines quality of service from the passenger point-of-view, but also describes the implications of different service levels from the transit provider point-of-view. The quality of service that passengers might consider to be optimal may not be cost-effective for a provider to offer; therefore, transit providers must balance quality of service, agency resources, and agency goals when designing and operating service.

The TCQSM identifies two main areas that influence transit quality of service: availability and comfort and convenience. The first two editions of the TCQSM measured quality of service using LOS letters, similar to the HCM, but the third edition dropped the letters in favor of presenting ranges of conditions where passengers experience a similar quality of service, with the number of levels not limited to six to match the standard A–F LOS lettering system. Changes in performance can be described in terms of how many levels that conditions changed relative to the base condition.

The TCQSM subdivides availability into temporal availability (frequency, how often service is provided, and hours of service, how long service is provided) and spatial availability (measured by the system's coverage of areas capable of supporting fixed-route bus service at a minimum 60-minute headway). These availability factors are generally set by transit agency policy and therefore cannot be forecast in the way, for example, traveler delay can be forecast based on a set of future conditions.

The TCQSM measures comfort and convenience through a combination of measures of on-board crowding, relative auto and transit travel time, and reliability. The first two measures lend themselves to forecasting, but quantitative methods for forecasting transit reliability have yet to be developed. The TCQSM acknowledges that other factors, such as driver friendliness and passenger perceptions of safety and security, also influence passenger ratings of quality of service, but cannot be forecast and are difficult to quantify except through passenger satisfaction surveys.

The TCQSM also presents the transit component of the HCM MMLOS method (described above), for use in comparing transit quality of service on a roadway to the quality of service provided to other travel modes on the roadway, and for users who desire a traditional LOS letter result.

The TCQSM provides methods for evaluating the operations of various transit modes, particularly their speed and capacity. These are intended primarily for use by transit agencies in planning their service and for transit and transportation planning agencies to evaluate the effects of transit-supportive roadway infrastructure. To the degree that transit speed is affected by service or infrastructure changes, some measures of passenger quality of service will also change.

Application and Data Needs

Evaluating the quality of service for existing conditions is straightforward for the frequency, level of service, and transit speed measures, simply requiring access to transit schedules. Measuring service coverage requires use of GIS software, but the necessary data should be readily available to any MPO. Passenger load and service reliability measures may be available from on-board passenger counters and automatic vehicle location equipment, if the transit agency archives these data; otherwise, a special data collection effort is required. Point-to-point auto speeds require modeling data, archived travel time data, or special data collection efforts. As noted above, forecasting future conditions generally requires making assumptions about future transit service, along with forecasting future ridership and transit speeds.

A spreadsheet for forecasting bus speeds is available online. It requires the following input data:

- For the critical bus stop on the facility (typically, the bus stop with the highest passenger volumes):
  - Average dwell time (can be input directly or estimated based on passenger volumes, fare collection method[s], and bus characteristics)
  - Coefficient of variation of dwell times
  - Design failure rate (percent of time a bus arrives to find all stopping positions already occupied)
  - Average green-to-cycle length ratio of the downstream signal (if present)
  - Traffic signal cycle length
  - Bus stopping position (in/out of the travel lane)
  - Bus stop location (near-side, far-side, mid-block influenced by nearby signals, mid-block not influenced by nearby signals)
  - Number of loading areas (number of buses that can stop simultaneously)
  - Area type (e.g., metro CBD)
  - Curb lane volume
  - Right-turn volume

    - Pedestrian volume conflicting with right turns
- For the facility:
    - Scheduled buses per hour
    - Average bus stop spacing
    - Number of traffic signals relative to number of bus stops (more/same or fewer)
    - Bus facility type (e.g., mixed traffic, bus lane with right turns allowed)
    - Maximum bus running speed between stops (typically the speed limit)
    - Skip-stop operation (yes/no), plus data on the stopping pattern if "yes"

Challenges

The primary challenge of the TCQSM is deciding which of its performance measures and methods are most applicable to a given analysis. The TCQSM's philosophy has been to present multiple measures, each of which can be directly measurable in the field, in contrast to the HCM's approach of selecting one measure as the best measure of quality of service. However, the TCQSM approach can create issues in presenting results, in that up to six QOS results can be reported, rather than one. In response to user requests for a single measure of transit LOS, the TCQSM 3rd Edition also presents the transit element of the HCM's MMLOS measure, which incorporates multiple factors, but produces an index value that cannot be directly measured in the field.

Opportunities

The comprehensive nature of the TCQSM makes it an excellent reference document, and an important tool for gaining a detailed understanding of transit quality and operations concepts with which to evaluate potential systems of performance evaluation.

Level of Traffic Stress (LTS) Analysis

Overview

The Level of Traffic Stress (LTS) methodology is used to predict how bicyclists will experience the road. Unlike the Bicycle Level of Service methodology, the LTS methodology takes into account the user tolerance for different types of facilities and traffic conditions, in which there are certain conditions that must be met for biking to be accessible to the mainstream public. The methodology uses a weighted compilation of traffic volume, traffic speed, number of travel lanes, roadway and lane width and presence of parking to determine an LTS classification of 1 through 4. "The *Level of traffic stress 1 (LTS 1) is meant to be a level that most children can tolerate; LTS 2, the level that will be tolerated by the mainstream adult population; LTS 3, the level tolerated by American cyclists who* *are "enthused and confident" but still prefer having their own dedicated space for riding; and LTS 4, a level tolerated only by those characterized as "strong and fearless."*[3]

The methodology is anchored by LTS 2, which mimics Dutch standards for acceptable bicycle conditions. This standard has been proven to be acceptable to most vulnerable users, and a robust network of LTS 1 and 2 facilities can serve most of the population.[4]

The methodology classifies bicycle facilities into 3 types: (1) physically separated bicycle facilities, (2) bicycle lanes, and (3) streets with mixed traffic. The most intensive part of the analysis is assigning an LTS to streets with mixed traffic. **Table 5** classifies street LTS based on two main data points: street width and speed.

Table 5: Criteria for Level of Traffic Stress in Mixed Traffic

Speed Limit	Number of Lanes		
	2-3 lanes	4-5 lanes	6+ lanes
Up to 25 mph	LTS 1 or 2*	LTS 3	LTS 4
30 mph	LTS 2 or 3*	LTS 4	LTS 4
35+ mph	LTS 4	LTS 4	LTS 4

*Note: Use lower value for streets without marked centerlines or classified as residential and with fewer than 3 lanes; use higher values otherwise.

(Source; Table 4 from MTI, P. 21)

While the LTS methodology takes into account roadway and traffic characteristics, which are central aspects that affect a person's decision to bike, it does not take into account other stressors, such as pavement quality, crime, noise, and aesthetics.[4]

Applications

The LTS methodology has been applied in several cities and counties to evaluate their systems and to develop either design guidance for projects or specific plans for projects and improvements. Montgomery County, MD developed a bicycle planning guide based on the LTS methodology. It used basic concepts of speed and traffic volumes to provide guidance on an appropriate bicycle facility that would meet most of the population's needs to bike based on the street context. The planning guide provided a case example in Bethesda, MD where the LTS methodology was used to evaluate the entire network and prioritize improvements to "unlock" the low-stress network.

The LTS methodology is best applied using link and intersection data within GIS. A GIS shapefile that has any combination of speed, volumes, number of lanes, and presence of parking can be used to map the LTS score for streets. This allows practitioners to easily evaluate the network and identify

[3] Maaza C. Mekuna, Ph.D. et al., *MTI Report 11-19: Low Stress Bicycling & Network Connectivity*, Mineta Transportation Institute: San Jose State University, 2012.

projects that would have the highest return in terms of "unlocking" low-stress islands of streets that already exist in the network.

The LTS can also evaluate the "connectivity" of the network by calculating the percentage of low-stress islands that are connected to each other via a low-stress facility.

Data Needs

Table 6 below summarizes the data used in the LTS methodology and how it is used to "inform" the LTS score.

Table 6: LTS Data Inputs

Data Set	Recommended or Required?	Purpose
Average Daily Traffic Volume	Required	This informs how much traffic exposure the bicyclist experiences.
Speed	Required (Observed speeds recommended when possible)	Speed provides a measure of the comfort a bicyclist experience when a vehicle passes in mixed traffic. Traffic speeds that exceed 30 mph are less tolerable by the majority of the population.
Number of Travel Lanes	Recommended	Number of travel lanes is a good indicator of traffic volumes when volume data are not available. The number of travel lanes and ADT can also highlight cases in the network where streets that are one-lane but experience 8,000+ ADT can move the needle from an LTS 1 or 2 to LTS 3. Although the street is one-lane and low speed, the peak-hour experience of having a steady stream of cars pass a bicyclist exceeds the majority of the population's traffic stress tolerance.
Presence of Parking	Recommended	The presence of parking is particularly needed for LTS 3 and 4 streets to determine an appropriate bicycle facility. In most conditions a bike lane is not acceptable between a parking lane and a travel lane.
Presence of a Bicycle Facility (and Type)	Required	The existing bicycle network is necessary to understand whether the road is stressful for bicyclist. The roadway characteristics can indicate an LTS 4 but the presence of a separated facility would classify that same corridor as an LTS 1. A cycle track, sidepath, or any facility physically separated from traffic and requires minimal attention from bicyclist would be rated an LTS 1. A local street with low traffic volumes and traffic speeds below 25 mph and a bike lane adjacent to the curb (no parking) would be an LTS 2 or 3, while a condition with no bicycle facility present or a facility that encourages mixing with traffic speeds over 30 mph would be an LTS 4.

Challenges

The LTS methodology requires relatively simple and available data points. The methodology application is usually in a mapping format in GIS. Developing a data set that has all the required and recommended data points in a link and intersection data set that can be mapped in GIS can be time consuming and expensive.

The methodology also heavily depends on speed data. In many cases, posted speed limits are more readily available than observed speeds. This can create misleading LTS scores, as posted speeds can be regularly exceeded by the daily traffic. In these cases, the results of the methodology usually require a higher quality "truth vetting" process with local stakeholders and practitioners.

Opportunities

The LTS methodology is a well digested methodology that provides a representation of the comfort of a bicycle and roadway network for bicyclist in the context of the majority of the population. It is also a methodology that steers the planning and design process from implementing bicycle facilities that "fit" in the right-of-way to context-appropriate design based on the traffic stress of the street.

Despite what can be an intense effort to compile data into a GIS format for mapping, the ability to map scores and use the LTS to look at overall connectivity in a network is helpful to practitioners as they focus and prioritize projects. This allows for practitioners to identify projects that leverage existing low stress streets and implement high-return facilities.

Bicycle Network Analysis (BNA) Score

Overview

The Bicycle Network Analysis (BNA) Score is a methodology that was recently developed by peopleforbikes as a way to measure how well the existing bicycle network connects people with places they want to go. The methodology combines a modified LTS approach with U.S. Census data and OpenStreetMap (OSM). The methodology compiles employment and household data to evaluate how the low-stress network is serving trips.

The methodology identifies census tracts that are accessible via the low-stress network within a 10-minute biking trip and assuming no more than a 25 percent route diversion. The total number of destinations accessible on the low-stress network compared with the total number of destinations that are within biking distance regardless of whether they are accessible via the low-stress network is calculated to understand the ratio of destinations accessible on the low stress bike network to those not accessible on the low stress bike network.

The methodology also takes into account types of destinations and assigns points on a scale of 0–100 for each destination type based on the number of destinations available on the low-stress network, as well as the ratio of low-stress destinations to all destinations within biking distance.[5]

The BNA's six scoring categories are:

- People
- Opportunity
- Core Services
- Recreation
- Retail
- Transit

Where there are mixed destination types, the category score is combined for both category place types. Weights for each destination type are used to represent their relative importance within the category. For census blocks where a destination type is not reachable by either high- or low-stress means, that destination type is excluded from the calculations. For example, the Opportunity score within a city with no institute of higher education is produced by excluding the Higher Education destination type so the score is unaffected by its absence[5].

The methodology uses weighted scores for each category to calculate one overall score. The weights of these score categories are provided in the table below. Once the weighted scores are compiled, they are normalized by the population to develop a score of 1 to 100.

Table 7: Scoring Category and Corresponding Weight

Scoring Category	Weight	Measure
People	15	Population
Opportunity	20	Employment
		K-12 education
		Technical/vocational school
		Higher education
Core Services	20	Doctor offices/clinics
		Dentist offices
		Hospitals
		Pharmacies
		Supermarkets
		Social services
Recreation	15	Parks
		Recreational trails
		Community centers
Retail	15	Retail shopping
Transit	15	Stations/transit centers

Application

The BNA score methodology is very new as it was only released in the past 6 months by peopleforbikes. The most relevant application has been a web-based tool that has calculated several cities' overall BNA score. A screenshot of the LTS map and BNA score (out of 100) for Tampa, FL is provided in **Figure 1**.

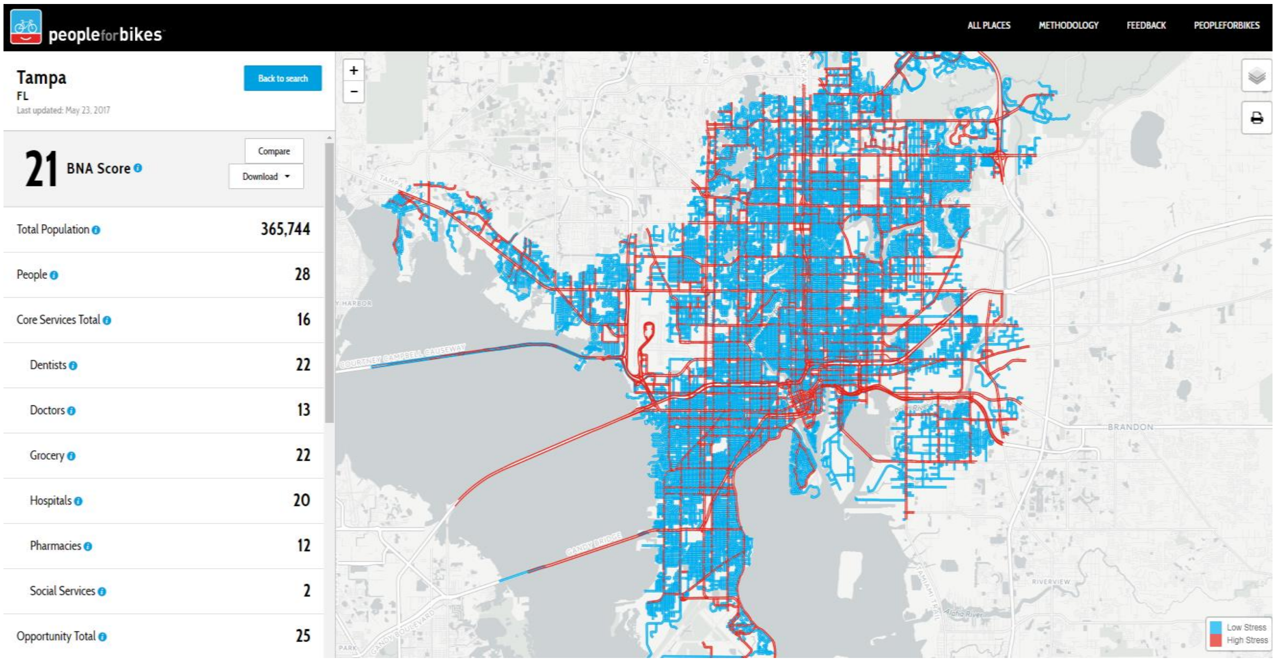

Figure 1: BNA Score and mapping for Tampa, FL from Peopleforbikes Web Tool, 2017

Data Needs

The BNA score combines the LTS analysis with publically available US census data. The more precise and accurate the data in the LTS analysis, the more likely the BNA score reflects reality. In the web tool, the BNA depends on OSM data, which tags segments and intersections with key data points that the analysis then streamlines into a "High" or "Low" stress rating. For instance, the presence of a cycle track indicates a low stress segment while any condition where bikes mix with traffic over 20 mph is a high stress segments. A summary of how facilities at the segment and intersection level are scored as "High" or "Low" is provided in **Table 8 and 9.** The only exception to these tables is in the case where a segment is classified as "residential" or "unclassified" in OSM. Almost all these cases include mixed traffic conditions where the segment is considered low stress as long as the speeds are less than 30 mph. The only cases where the segment would be high stress is in two cases where the speed limit is 25 mph and (1) there is one travel lane, parking on one side of the street, and the road width is less than or equal to 18 feet, or (2) there is one travel lane with parking on both sides of the street and the road width is less than or equal to 26 feet.

[5] Website: https://bna.peopleforbikes.org/#/methodology, 2017

Table 8: Segment Stress Based on Bicycle Facility and Roadway Characteristics

Facility Type	Speed (mph)	Number of Lanes	Parking	Facility Width	Stress
Cycle track					Low
Buffered bike lane	> 35	> 1			High
		1			High
	35	> 1			High
		1	Yes		High
			No		Low
	30	> 1	Yes		High
			No		Low
		1			Low
	<= 25				Low
Bike lane without parking	>30				High
	25-30	> 1			High
		1			Low
	<= 20	> 2			High
		<= 2			Low
Bike lane with parking				>= 15 ft	*Treat as buffered lane*
				13-14 ft	*Treat as bike lane without parking*
				< 13 ft	*Treat as shared lane*
Shared lane	<= 20	1			Low
		> 1			High
	> 20				High

Table 9: Intersection Stress Based on Bicycle Facility and Roadway Characteristics

Intersection Control	Number of Crossing Lanes	Crossing Speed Limit	Median Island	Stress
None/yield to cross traffic	> 4			High
	4	>30		High
		30	Yes	Low
			No	High
		<= 25		Low
	< 4	> 30	Yes	Low
			No	High
		<= 30		Low
RRFB	> 4			High
	4	>= 40		High
		35	Yes	Low
			No	High
		<= 30		Low
	< 4	> 35	Yes	Low
			No	High
		<= 35		Low
Signalized, HAWK, four-way stop, or priority based on class				Low

US census data are used to evaluate how well the LTS network connects places and people at the census tract level. The census tract data applied include:

- Population
- Employment
- K-12 education
- Technical/vocational schools
- Higher education
- Doctor offices/clinics
- Dentist offices
- Hospitals
- Pharmacies
- Supermarkets
- Social services

- Parks
- Recreational trails
- Community centers
- Retail shopping
- Stations/transit centers

The required US census data are available online by downloading the census tract GIS shapefiles.

Challenges

The BNA score is a new application; therefore, challenges and opportunities are still being identified and confirmed. The most apparent challenge is the street data set that informs the LTS in the web-based tool uses a flexible data set, OSM, which anyone can contribute to, introducing biases. While OSM is free, publically available, and fairly good for some cities, for many others it is non-existent or incomplete, limiting the jurisdictions that can use the web-based tool.

The BNA score also evaluates connectivity based on a 10-minute bicycle trip. Research has shown that people on bikes are usually willing to travel up to 3 miles by bike, which exceeds the 10-minute trip threshold. This also does not show a high return for a longer, high-quality facility that connects two major destinations that are more than 10 minutes apart. The BNA score, for instance, would show that a separated facility on a long bridge does not have a high impact on the connection between two communities on either side of the bridge if it is longer than a 10-minute trip by bicycle. The analysis also does not consider some recreational trips, such as connectivity to nightlife. Lastly, the methodology is limited to network applications versus a specific corridor or project.

Opportunities

The BNA score is the first bicycle planning methodology to incorporate land use and destinations into the planning process in a computational way. The methodology evaluates the network and streets based on how well people are connected to places and opportunities. This gives a fairly comprehensive look at how well the overall network is serving its adjacent land uses and helps practitioners identify and prioritize improvements that will serve those needs.

Charlotte's Pedestrian/Bike LOS (PLOS and BLOS)

Overview

The Charlotte Department of Transportation (CDOT) developed a methodology to evaluate the level of service for pedestrians and bicyclists at intersections based on design features. The key design features considered include crossing distance, roadway space allocation to crosswalks, bike lanes, sidewalks, medians, corner radius, and traffic signal characteristics. The methodology provides a point rating based on certain design elements. Design elements that are less comfortable for bicyclists and pedestrians receive lower points, and in some cases negative points, while design elements that are favorable for bicycles and pedestrians receive more points. The sources for each category are compiled into one final score. The methodology provides a range of points for LOS A through F, and the intersection is assigned a P/BLOS letter based on where its composite score falls in the pre-determined ranges.

Application

CDOT has applied this methodology as part of their small-area planning efforts and intersection prioritization processes. The City calculates P/BLOS for all signalized intersections in the City to assist in evaluating whether the intersection design features are serving the basic needs of pedestrians and bicyclists. At the moment, CDOT uses a spreadsheet tool to calculate the P/BLOS for every signalized intersection in the City.

Data Needs

The data for the P/BLOS calculations can be extrapolated from as-built plans, Google Earth measurements, and field measurements and observations.

The data required to calculate the PLOS include:

- The number of travel lanes to cross and the presence and width of a median refuge.
- Pedestrian signal phase that conflicts with a left turn or right turn.
- Pedestrian signal display details, such as whether a pedestrian signal is present and if so whether there is a leading pedestrian interval, a countdown display, and whether the Flash Down Walk/Countdown phase accommodates a walking speed of less than or equal to 3.5 ft./sec.
- Corner radius or the characteristics of a pedestrian refuge, when present.
- Presence of a NO RIGHT TURN ON RED sign.
- Crosswalk type, such as raised crosswalks, high visibility (zebra stripe), or low visibility (only two parallel lines), and crosswalk presence.

The data required to calculate the BLOS includes:

- Presence of a bike lane on the approach.
- Traffic speeds on the approach.
- Left-turn signal phasing.
- Stop bar location.
- Right-turn conflict and whether right turns are permitted on red.
- Number of travel lanes a bicyclist must cross.

The CDOT developed tables where scores were assigned based on the relative characteristics of each of these data points. The scores are combined for one total score and the methodology provides a corresponding LOS with each score.

Challenges

The methodology provides an objective measure to help understand the tradeoffs of a project against traditional vehicle measures (e.g., volume/capacity ratio), but the P/BLOS cannot be compared directly to auto LOS. The P/BLOS methodology assesses design features that affect comfort and safety, while the automobile LOS assesses delay, a measure of convenience. This makes it difficult to use the methodology to determine the trade-offs for different design decisions since the results of the metrics do not use the same scale. For instance, an auto LOS C is typically considered an acceptable performance for an urban intersection. However, a LOS C for the P/BLOS does not always translate to a design condition that most of the population will tolerate.

For instance, the BLOS methodology would assign LOS D to an approach with a 12-foot shared travel lane, a speed of 35 mph, a protected opposing left turn, right-turns on red, and 4 travel lanes to cross. Recent research has shown that this condition would not be tolerable for most of the population to ride a bike.

Opportunities

The methodology allows practitioners to assess how certain improvements will affect pedestrian and bicycle level of comfort on a project and intersection level. Practitioners can evaluate which design elements will have the highest impact, and the magnitude of points allocated seems to correlate with the magnitude of impact the treatments will have relative to each other. For instance, for PLOS, the scoring gives three times as many points for reducing left- and right-turn conflicts as implementing textured or high-visibility crosswalks.

CONCLUSION

This white paper has summarized five methodologies that can be used to quantify multimodal experiences along and across roadways. Some of the methodologies explored, such as the HCM MMLOS, provide a way to compare all four modes; while, other methodologies, such as the LTS, are tailored for one mode. Likewise, some methodologies can be applied at the project level to evaluate trade-offs, while others focus more on network-level evaluation to aid in project identification and prioritization. **Table** summarizes the mode, analysis level, and application for each methodology explored and provides an overview of the data needs and relative difficulty of application.

Table 10: Summary of Multimodal Methodology Applications

Methodology	Mode				Analysis Level			Data Needs	Difficulty	Application (Project or Network Level)
	Ped.	Bicycle	Transit	Auto	Intersection	Corridor	Network			
HCM Multi-Modal Level Of Service (MMLOS)	●	●	●	●	●	●	●	High*	High	Project or Network
Level of Traffic Stress (LTS)	○	●	○	○	◐	●	●	High	High	Project or Network
Bicycle Network Analysis (BNA) Score	◐	●	○	○	○	○	●	Low	Low	Network
Transit Capacity & Quality of Service Manual (TCQSM)	○	○	●	○	●	●	●	Varies	Varies	Varies
Charlotte PLOS and BLOS	●	●	○	○	●	○	○	Low	Low	Project or Network

● Meets the Need ◐ Partially Meets the Need ○ Does Not Meet the Need

*Agencies can rely on default values for many inputs to reduce the data requirements.

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Appendix A Interview Notes

Hillsborough MPO MMLOS White Paper: Sister MPO Interview

City: Charlotte DOT
Interview Attendees: Scott Curry (CDOT), Tracy Newsome (CDOT), Brett Boncore (KAI), Caitlin Doolin (KAI), Jennifer Musselman (KAI)
Date: June 15, 2017

Tracy Newsome is a transportation planner with the Charlotte Department of Transportation (CDOT). She was one of the main authors of the City's Urban Street Design Guidelines (USDG), which were developed in the mid-2000s. The P/BLOS methodology came from the USDG. She is heavily involved in policy development, area plans, and implementation of the capital program.

Scott Curry is an urban design and Pedestrian Program Manager for CDOT. He is responsible for the walkability initiative and manages the pedestrian program – funding from city council to build crosswalks and sidewalks.

1. **What is your agency's role in project development and decisions regarding modal trade-offs within projects? How is funding allocated to the projects you develop and manage?**

- CDOT handle many types of projects within city limits and works with the state on state maintained roadways.
- CDOT performs a lot of the modeling work for the CRTPO and works with them on the LRTP get projects on the priority list.
- There are a lot of different funding sources and programs.
  - CDOT has a history of putting forth bonds and getting them approved by the public.
  - CDOT has spent about $450M of city funds on complete streets improvements.
  - The pedestrian program gets about $7.5M every year from bonds, which come out every two years.
- CDOT tries to be opportunistic and always looks for opportunities to partner to get more projects done and done more quickly.

2. **What is the planning and design process for capital projects? How do you determine modal priority within a project?**
   - At least one representative from planning and design is on every CDOT project.
   - The USDG contains a six step planning and design process and the P/BLOS methodology. CDOT has used this process for the last 10 years
   - Now, the idea of complete streets and modal trade-offs is institutionalized. The process is so ingrained; engineers and planners have the same expectations. Trade-off discussions don't need to happen explicitly anymore. There is still a trade-off discussion that uses some form of the 6-step process (such as surrounding land use and constructability). There is a systematic and purposeful discussion on what needs to happen on every project.
   - CDOT tries to get a minimal level of pedestrian and bicycle facility in every widening project. Retrofits are more difficult but there is still an expectation CDOT will try to incorporate ped/bike facilities.

- CDOT has a street classification system (boulevards, avenues, parkways, etc.) and within those classifications there are different expectations for what ped and bike infrastructure should look like. For examples, if something is designated as a main street, the pedestrian is the priority. As you move toward a parkway, the auto is more emphasized
- The classification is a human-based assessment that relies on data (GIS, volume, lanes, bike/ped LOS when available).
- CDOT developed a classification for each street on the thoroughfare plan. They take advantage of ongoing/upcoming studies to update the initial classification and do more detailed planning and design.

3. **What tools do you use to evaluate how well the network is serving pedestrians, bicycles and/or transit? What criteria/methodology is used to determine the LOS for each mode?**
   - At the beginning of every project, they start with USDG and goals for the project.
   - CDOT does not use BLOS and PLOS on every project. It is a tool they use to support decisions. It was used more when USDG and complete streets were newer.

4. **How has the Pedestrian LOS methodology affected project decisions and selection (both negative and positive)?**
   - CDOT maintains B/PLOS and uses the data to describe existing conditions when doing an area plan. CDOT analyzes P/BLOS for signalized intersections as part of area plans. There is a spreadsheet to help with calculation. BLOS/PLOS is then used to prioritize which intersections need to make their way to a project. CDOT looks at congestion, safety, PLOS, BLOS, and multimodal connectivity to rank intersection projects.

5. **How does the City's Pedestrian LOS methodology take into account intersection capacity?**
   - Every project still looks at vehicular capacity and a v/c ratio. The majority of residence are still using automobile to get around.
   - CDOT has done 30 road diets in the city. They started with the 'easier' ones. There are no set thresholds on when to consider road diets, but the accepted volumes are marching higher now that they've picked off the low hanging fruit.
   - CDOT has found a sliding scale for acceptance of congestion on different types of facilities. Residents expect speeds to be slower on main streets.
   - CDOT has started looking at the length of the peak hour to see how long congestion is lasting and has found that residents can accept a longer peak hour in some cases.
   - There is more congestion on suburban roads where this is not as much network

6. **How long have you been using your current process? What is attractive or compelling about the process you currently use to evaluate projects and/or the transportation network? Does the process have any shortcomings?**

   - CDOT has been using the USDG for the past 10 years and has gotten some great projects.
   - The process was based on assumption that we were not going to make things worse for motorists, only better for cyclists. There are cases where the community is asking for things that are not an option. CDOT has reached a point where the improvements needed to increase capacity are not palatable to the community and they are needing to make more tradeoffs between vehicular and bike/ped.

- There is a healthy tension between staff focused on different modes.
- Some projects have accepted higher congestion for short periods or certain circumstances
- CDOT sometimes has a harder time having the trade-off conversation on NCDOT roads.

Hillsborough MPO MMLOS White Paper: Sister MPO Interview

Agency: FHWA
Interview Attendees: Dan Goodman (FHWA), Caitlin Doolin (KAI), Jennifer Musselman (KAI)
Date: 6/20/2017

1. **What is your agency's role in project development and decisions regarding modal trade-offs within projects? How is funding allocated to the projects you develop and manage?**
   - FHWA's role is in the planning process. They provide guidance and setup the conditions for a good planning process. One outcome of a good planning process is a way to prioritize projects. FHWA shares information on methodologies so agencies can create good project prioritization.
   - A lot of prioritization happens for the Transportation Alternatives Program (TAP). FHWA sets up the rules of the game and makes sure everyone follows them.
   - FHWA recently published guidebook for bike/ped performance measures. Those measures could be used for project prioritization. The guidebook links measures with a community's goals. For each measure, there are examples of how to track the measure.
   - NCDOT has done some good prioritization work.
   - NCHRP research project 07-17 provides guidance on project selection and prioritization.

2. **What has the Multi-Modal Network study FHWA is leading revealed to date? Are there any common themes of where cities are struggling and succeeding in terms of evaluating multi-modal projects?**
   - Dan will send a literature review from the network work done in Baltimore. The report will be published in the fall.

3. **How are cities considering trade-offs for projects between different modes? How does vehicle capacity factor into those considerations?**

   - There will always be a comparison to traditional LOS. Folks are acknowledging that vehicular LOS can be a helpful input into the planning process but we need to understand what it is, and is not, telling us. We can't use it to extrapolate everything in the system. We need other things to get a holistic understanding of everything that goes into the planning process.
   - Dan will share a white paper on this topic if it's public.

4. Have you ever applied the HCM's MMLOS methodology to evaluate projects or the transportation network? If so, what were its strengths? What were its shortcomings?

   - MMLOS and P/BLOS are helpful inputs. A lot of people are using them and they are informing things in a helpful way.
   - BLOS is based on research that was done quite a while ago in Florida. It was done on field analysis. At that point, no one was building separate bike lanes and cycle tracks. The methodology is not refined enough for today's conditions.
   - It is hard to move the needle for P/BLOS. Widening the sidewalk, for examples, shows little benefit in the analysis.

5. Have you ever applied the Level of Traffic Stress methodology to projects or to evaluate the network? If so, what were its strengths? What were its shortcomings?
    - There was a white paper published last month on low stress network for bikes.
    - Martha/Kyle developed an algorithm to measure low stress connectivity. An agency inputs open street map data into the tool and it measures connectivity for the community. The output is only as good as the data going in. The current methodology can be expensive and time consuming to run all the data and keep it up to date. This tool may be a way to get around that.

   Recommendation for follow-up discussions: Colorado DOT (Betsy Jacobson), Washington DOT, Minneapolis MPO and Philadelphia MPO.

Hillsborough MPO MMLOS White Paper: Sister MPO Interview

Agency: SANDAG
Interview Attendees: Mike Calandra (SANDAG), Sarah McKinley (Hillsborough MPO), Caitlin Doolin (KAI), and Jennifer Musselman (KAI)
Date: 7/11/17

Questions:

1. Please describe your role within SANDAG.

   Mike Calandra is a travel demand modeler and model application specialist with SANDAG. He runs the model for SANDAG plan updates and to support local jurisdictions and consultants in their planning efforts.

   SANDAG has a service bureau that is the consulting arm and allows us to contract to external partners. SANDAG has 19 member agencies. The service bureau is on standby to help any of the member agencies. For local jurisdictions the work is usually city/community wide or for a corridor. On the private side, projects are usually for a specific site.

2. What type of methodologies do you apply when modelling? Have you ever applied the HCM's MMLOS methodology to evaluate projects or the transportation network? If so, what were its strengths? What were its shortcomings?

   SANDAG uses an activity based model. Mike uses the model to perform network and land use analysis. SANDAG can do custom scenarios in one or both areas. Mike recommended taking an incremental approach and change one thing at a time. Network changes are usually highway or arterial related and can be transit related.

   Modeling the active transportation network is a new paradigm. The model currently does not have ped/bike assignments. When they change the active transportation network changes can't be seen on a link level but can be seen in overall mode choice. The active network focuses on bicycle classifications. Changes in classification have small changes in mode choice output. Adding/removing bicycle links have a larger impact on the mode choice. A similar analysis does not yet exist for pedestrian infrastructure.

   Active transportation modeling is best applied at the community or city level where there are more opportunities to change the network and see changes in the results. The model is used for both needs identification and project identification. The city can use the model to prioritize infrastructure within the community. At the regional level, SANDAG uses the model to prioritize highway/arterial, transit, and active projects.

   SANDAG uses the model and HCM procedures to find capacity on highways and arterials. Consultants may use model outputs to perform their own MMLOS calculation, but SANDAG does not do the calculations.

3. How long have you been using your current process? What is attractive or compelling about the process you currently use to evaluate projects and/or the transportation network? Does the process have any shortcomings?

   The biggest issue with model calibration is the amount of data required. There is lack of information on arterials. For freeways, Caltrans has a performance monitoring system that continuously being collects volume and speed data. For transit, SANDAG has a count system and is moving toward APC data. Arterials are under the jurisdiction of each city. Some cities have not done traffic counts for 10+ years.

4. Is SANDAG exploring use of performance measures beyond LOS?

   The State of California removed LOS from legislature and replaced it with VMT. There are no guidelines on how to do it just yet, and every jurisdiction is doing it a little bit differently. SANDAG is starting to report VMT for every project. They have the ability to use the model to pull the VMT apart by origins and destinations. Adding active transportation links in the model is a way to mitigate VMT. There is no one size fits all approach for the VMT trade-off of bicycle infrastructure. In the activity based model, adding a bike facility in an urban or rural context will have different effects on VMT.

Appendix B HCM MMLOS Sample Default Values

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 825

Planning and Preliminary Engineering Applications Guide to the Highway Capacity Manual

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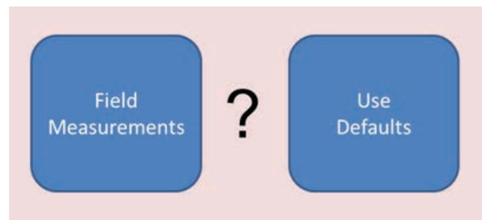
F. Default Values to Reduce Data Needs

1. Overview



Many HCM computational methods require a number of input parameters. For a detailed operations analysis, this can be an advantage, as the performance measure output by the method reflects many different factors that can influence the result. However, for planning and preliminary engineering analyses, the number of inputs can pose a challenge. The desired information may not yet be known, the level of effort required to gather the data may be out of proportion to the aims of the analysis, or a combination of these and other considerations can make it difficult to supply a particular input value.

One solution to applying HCM methods to planning and preliminary engineering analyses is to substitute *default values* for those inputs that cannot be measured directly. Using default values instead of field-measured values may introduce some error into the analysis results, but other data used for planning analyses (particularly forecast demand volumes) may have much greater uncertainties associated with their values and, consequently, much greater impact on the results. Furthermore, the goal of these types of analyses is not to make final decisions about roadway design and control elements, but rather to identify potential problems or to screen large numbers of alternatives; in these cases, precise results are neither required nor expected.

It is important to recognize that HCM input data have a hierarchy that varies according to the context of the planning and preliminary engineering application: There are applications where certain input data can be and must be measured. (These data are identified as "required inputs" in subsequent sections.) There are planning and preliminary engineering applications where certain input data can and should be estimated sensibly based on local and planned conditions; Section F4 addresses this situation. Finally, as discussed in Section F2, there are applications where certain data need not be measured and a general default value can be used instead. Parts 2 and 3 of the Guide provide simple default values for analysis situations where the analyst has deemed a locally measured value is not necessary.

This section provides guidance on applying default values to HCM methods and on developing local default values to use in place of the HCM's national defaults.

2. When to Consider Default Values

The decision to use a default value in place of a field-measured value should consider a number of factors, including:

- **The intended use of the analysis results.** In general, the less precisely that analysis results will be presented (e.g., under, near, or over capacity versus a particular LOS versus a specific travel speed estimate), the more amenable the analysis is to using default values, or tools based on default values, such as service volume tables. Similarly, the farther away a final decision is (e.g., identifying potential problem areas for further analysis versus evaluating a set of alternatives versus making specific design decisions), the less potential exists for incorrect decisions to be drawn from the analysis results due to the use of a default value.

- **The scale of the analysis.** The larger the geographic scale of the analysis (i.e., the greater the number of locations that need to be analyzed), the greater the need to use default values due to the impracticality of collecting detailed data for so many locations.
- **The analysis year.** The farther out into the future that conditions are being forecast, the more likely that information will not be known with certainty (or at all), and the greater the need to apply default values.
- **The sensitivity of the analysis results to a particular input value.** Sections H through O of this Guide provide information about the sensitivity of analysis results to the inputs used by a given HCM operations method. Input parameters are characterized as having a low, moderate, or high degree of sensitivity, depending on whether a method's output changes by less than 10%, 10% to 20%, or more than 20%, respectively, when an input is varied over its reasonable range. The lower the result's sensitivity to a particular input, the more amenable that input is to being defaulted.
- **Ease of obtaining field or design data.** According to the HCM (2016), input parameters that are readily available to the analyst (e.g., facility type, area type, terrain type, facility length) should use actual values and not be defaulted.
- **Inputs essential to an analysis.** A few inputs to HCM methods, such as demand volumes and number of lanes, are characterized as "required inputs" and should not be defaulted. When the purpose of the analysis is to determine a specific value for a required input (e.g., the maximum volume for a given LOS), the HCM method is run iteratively, testing different values of the input until the desired condition is met.
- **Local policy.** State and local transportation agencies' traffic analysis guidelines may specify that particular inputs to HCM methods can or should not be defaulted.

3. Sources of Default Values

Once a decision has been made to use a default value for a particular methodological input, there are several potential sources for obtaining a default value. These are, in descending order of desirability according to the HCM (2000):

- **Measure a similar facility in the area.** This option is most applicable when facilities that have not yet been built are being analyzed and the scope of the analysis does not require measuring a large number of facilities.
- **Local policies and standards.** State and local transportation agencies' traffic forecasting guidelines may specify, or set limits on, default values to assume. Similarly, these agencies' roadway design standards will specify design values (e.g., lane widths) for new or upgraded roadways.
- **Local default values.** When available, local default values will tend to be closer to actual values than the HCM's national defaults. Heavy vehicle percentage, for example, has been shown to vary widely by state and facility type (Zegeer et al. 2008). The next subsection provides guidance on developing local default values.
- **HCM default values.** If none of the above options are feasible, then the HCM's national default values can be applied.

4. Developing Local Default Values

This section is adapted from HCM (2016), Chapter 6, Appendix A.

Local defaults provide input values for HCM methods that are typical of local conditions. They are developed by conducting field measurements in the geographic area where the values will be applied, during the same time periods that will be used for analysis, typically weekday peak periods. For inputs related to traffic flow and demand, the peak 15-minute period is recommended as the basis for computing default values because this time period is most commonly used by the HCM's methodologies.

When an input parameter can significantly influence the analysis results, it is recommended that multiple default values be developed for different facility types, area types, or other factors as appropriate, as doing so can help reduce the range of observed values associated with a given default and thus the error inherent in applying the default. The *K*- and *D*-factors used to convert AADT volumes to directional analysis hour volumes are two such parameters. For urban streets, other sensitive parameters include peak hour factor, traffic signal density, and percent heavy vehicles. For freeways and highways, sensitive parameters include free-flow speed and peak hour factor.

5. References

Highway Capacity Manual: A Guide to Multimodal Mobility Analysis. 6th ed. Transportation Research Board, Washington, D.C., 2016.

Highway Capacity Manual 2000. Transportation Research Board, National Research Council, Washington, D.C., 2000.

Zegeer, J. D., M. A. Vandehey, M. Blogg, K. Nguyen, and M. Ereti. *NCHRP Report 599: Default Values for Highway Capacity and Level of Service Analyses.* Transportation Research Board of the National Academies, Washington, D.C., 2008.

K. Urban Streets

1. Overview

Any street or roadway with signalized intersections, STOP-controlled intersections, or roundabouts that are spaced no farther than 2 miles apart can be evaluated using the HCM methodology for urban streets and the procedures described in this section.

The planning methods for urban streets focus on facility-level analysis, segment-level analysis, and intersection-level analysis. Facility-level performance is estimated by summing the segment (between intersections) and intersection performance results.

Interchange ramp terminals are a special case of intersection at the foot of freeway on- and off-ramps. They are addressed in HCM Chapter 23. The uneven nature of lane demands and the tight spacing between signals within a freeway interchange result in conditions that are not typical of an urban street.

An urban street segment is a segment of roadway bounded by controlled intersections at either end that require the street's traffic to slow or stop. An urban street facility is a set of contiguous urban street segments. The control delay at the downstream intersection defining a segment is included in the segment travel time. Exhibit 43 shows the relationship between an urban street facility, an urban street segment, and an intersection, as well as the segment travel time and intersection control delay.

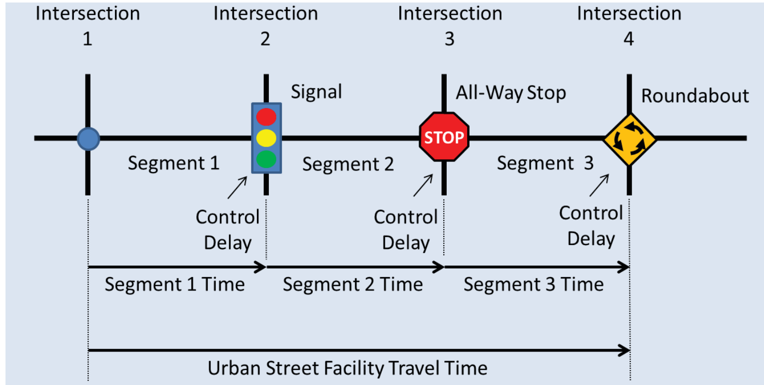
The exhibit shows only one direction of a typical bi-directional urban street analysis.

2. Applications

The procedures in this chapter are designed to support the following planning and preliminary engineering analyses:

- Development of an urban street corridor improvement plan
- Feasibility studies of
  - Road diets,
  - Complete streets,
  - Capacity improvements,
  - Signal timing improvements,
  - Transit priority timing, and
- Land development traffic impact studies.

Exhibit 43. Relationships between urban street facility, urban street segments, and intersections.



3. Analysis Methods Overview

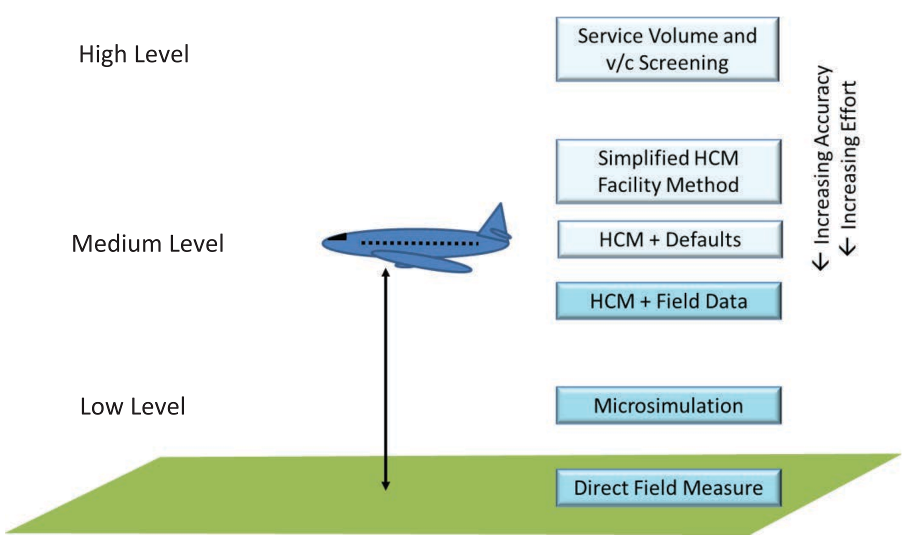
Urban street performance can be directly measured in the field or it can be estimated in great detail using microsimulation. However, the resource requirements of both of these methods render them generally impractical for most planning and preliminary engineering applications.

The HCM provides a less resource-intensive approach to estimating urban street performance; however, it also is generally impractical to use the HCM with 100% field-measured inputs for many planning and preliminary engineering analyses.

As shown by the unshaded boxes in Exhibit 44, this section presents two medium-level methods for evaluating urban street performance, as well as a high-level screening and scoping method that can be used to focus the analysis on only those locations and time periods requiring investigation.

The HCM facility, segment, and intersection analysis methods (covered in HCM Chapters 16 to 23) provide a good basis for estimating urban street performance under many conditions. However, these methods are complex and specialized software is required to implement them. Consequently, a simplified HCM facility analysis method is presented in this section to reduce the number of computations and to enable programming of the method in a static spreadsheet, without requiring writing macros to implement it.

Exhibit 44. Analysis options for urban streets.



Because all of these methods still require a fair amount of data and computations, this chapter also provides a high-level service volume and volume-to-capacity ratio screening method for quickly identifying which portions of the street will require more detailed analysis (to properly account for the spillover effects of congestion), and to quickly compare improvement alternatives according to the capacity they provide.

4. Scoping and Screening

Generalized Service Volume Tables

Whether or not a more detailed urban street facility analysis is needed can be determined by comparing the counted or forecasted daily or peak hour traffic volumes for the urban street segments between each controlled intersection to the values given the service volume tables presented later in this subsection. If all of the segment volumes fall in the LOS E range or better, there will not be congestion spillover requiring a full facility analysis to better quantify the facility's performance. One can then use the HCM intersection and segment analysis procedures with defaults for some of the inputs to evaluate the performance of each segment and intersection.

The service volumes can also be used to quickly determine the geographic and temporal extent of the urban street facility that will require analysis. If the counted or forecasted volumes for a segment fall within the agency's target LOS standard, then the segment and its associated downstream intersection can be excluded from a more detailed analysis.

HCM Daily Service Volume Table

HCM Exhibit 16-16 (adapted below as Exhibit 45) provides approximate maximum two-way AADT volumes that can be accommodated by an urban street at a given LOS for two posted speed limits under very specific assumptions of signal timing, signal spacing, access point (unsignalized driveway) spacing, and access point volumes. The service volumes are highly sensitive to the selected assumptions.

Alternative Daily and Peak Hour Service Volume Table

Exhibit 46 provides maximum service volumes (both two-way AADT and peak hour peak direction) that can be accommodated by an urban street under differing assumptions regarding signal timing, signal spacing, and facility length. The values in this table are expressed on a per-lane basis. For example, a six-lane urban street (three lanes each direction) can carry between 52,200 (8,700 × 6 lanes) and 81,600 AADT (13,600 × 6 lanes) at LOS E, depending on the posted speed limit, signal spacing, and traffic signal cycle length. The LOS E service volume is generally also the through capacity at the critical signal on the facility; however, in some situations (as noted in the chart), this volume may be lower than the capacity.

Intersection Volume-to-Capacity Ratio Checks

The problem with screening at the facility level is that it is possible for the service volume check to show LOS E for the facility when the capacity of one or more intersections along the street has already been exceeded. This condition is especially likely when the signals are widely spaced (i.e., more than one-quarter mile apart). Thus, an intersection volume-to-capacity (v/c) ratio check is recommended to supplement the overall facility service volume screening.

The intersection v/c ratios are computed and screened using the methods described in the intersection sections of this Guide (Section L for signalized intersections, Section M for STOP-controlled intersections, and Section N for roundabouts). The v/c ratios may be used for study

Exhibit 45. HCM daily service volume and capacity table for urban streets.

K-Factor	*D*-Factor	Two-Lane Streets			Four-Lane Streets			Six-Lane Streets		
		LOS C	LOS D	LOS E	LOS C	LOS D	LOS E	LOS C	LOS D	LOS E
Posted Speed Limit = 30 mph										
0.09	**0.55**	1,700	11,800	17,800	2,200	24,700	35,800	2,600	38,700	54,000
0.09	**0.60**	1,600	10,800	16,400	2,000	22,700	32,800	2,400	35,600	49,500
0.10	**0.55**	1,600	10,700	16,100	2,000	22,300	32,200	2,400	34,900	48,600
0.10	**0.60**	1,400	9,800	14,700	1,800	20,400	29,500	2,200	32,000	44,500
0.11	**0.55**	1,400	9,700	14,600	1,800	20,300	29,300	2,100	31,700	44,100
0.11	**0.60**	1,300	8,900	13,400	1,700	18,600	26,900	2,000	29,100	40,500
Posted Speed Limit = 45 mph										
0.09	**0.55**	7,700	15,900	18,300	16,500	33,600	36,800	25,400	51,700	55,300
0.09	**0.60**	7,100	14,500	16,800	15,100	30,800	33,700	23,400	47,400	50,700
0.10	**0.55**	7,000	14,300	16,500	14,900	30,200	33,100	23,000	46,500	49,700
0.10	**0.60**	6,400	13,100	15,100	13,600	27,700	30,300	21,000	42,700	45,600
0.11	**0.55**	6,300	13,000	15,000	13,500	27,500	30,100	20,900	42,300	45,200
0.11	**0.60**	5,800	11,900	13,800	12,400	25,200	27,600	19,100	38,800	41,500

Source: Adapted from HCM (2016), Exhibit 16-16.

Notes: Entries are maximum vehicle volumes per lane that can be accommodated at stated LOS.

AADT = annual average daily traffic. AADT per lane is two-way AADT divided by the sum of lanes in both directions.

This table is built on the following assumptions:

- No roundabouts or all-way STOP-controlled intersections along the facility.
- No on-street parking and no restrictive median.
- Coordinated, semi-actuated traffic signals, with some progression provided in the analysis direction (i.e., arrival type 4).
- 120-second traffic signal cycle lengths, protected left-turn phases provided for the major street, and the weighted average g/C ratio (i.e., ratio of effective green time for the through movement in the analysis direction to the cycle length) = 0.45.
- Exclusive left-turn lanes with adequate queue storage are provided at traffic signals and no exclusive right-turn lanes are provided.
- 2-mile facility length.
- At each traffic signal, 10% of traffic on the major street turns left and 10% turns right.
- Peak hour factor = 0.92 and the base saturation flow rate = 1,900 pc/h/ln.
- Additional assumptions for 30-mph facilities: signal spacing = 1,050 ft and 20 access points/mi.
- Additional assumptions for 45-mph facilities: signal spacing = 1,500 ft and 10 access points/mi.

scoping purposes to identify those intersections requiring more detailed analysis. They may also be used to quickly screen capacity-related improvement alternatives.

Any segment that exceeds the capacity of the downstream intersection will have queuing that may impact upstream segments and reduce downstream demands. In such a situation, a full urban street facility analysis using a method capable of accurately identifying queue spillbacks is required to ascertain the performance of the urban street. The facility analysis can be performed using the HCM method with defaults, described later in this section. In cases of severe congestion, a microsimulation analysis may be required to accurately assess queue spillback effects.

The analyst may also use the intersection demand-to-capacity (d/c) ratios for each segment to quickly screen various capacity improvement options. Exhibit 47 shows the planning capacities per through lane that may be used to screen for signalized intersection capacity problems. The options can then be quickly ranked according to their forecasted d/c ratios for the critical segments of the urban street.

Exhibit 46. Daily and peak hour service volume and capacity table for four-lane urban streets.

Speed Limit (mph)	Signal Spacing (ft)	Cycle Length (s)	Peak Hour Peak Direction (veh/h/ln)			AADT (2-way veh/day/ln)		
			LOS C	LOS D	LOS E (capacity)	LOS C	LOS D	LOS E (capacity)
25	**660**	**90**	630	840	940	5,800	7,800	8,700
25	**1,320**	**120**	1,000	1,100	1,100	9,300	10,200	10,200
35	**1,320**	**120**	820	1,040	1,100	7,600	9,600	10,200
35	**2,640**	**180**	1,300	1,360	1,460	12,000	12,600	13,500
45	**1,320**	**180**	630	1,180	1,300*	5,800	10,900	12,000*
45	**2,640**	**180**	1,220	1,320	1,400*	11,300	12,200	13,000*
55	**2,640**	**180**	1,240	1,320	1,380*	11,500	12,200	12,800*
55	**5,280**	**180**	1,340	1,430	1,470	12,400	13,200	13,600
55	**10,560**	**180**	1,470	1,470	1,470	13,600	13,600	13,600

Notes: *The LOS F speed threshold is reached before the through movement volume-to-capacity (v/c) ratio reaches 1.00. In all other cases, the v/c ratio limit of 1.00 for LOS F controls.

Entries are maximum vehicle volumes per lane that can be accommodated at stated LOS.

AADT = annual average daily traffic. AADT per lane is two-way AADT divided by the sum of lanes in both directions.

This table is built on the following assumptions:

- Four-lane facility (two lanes in each direction).
- No roundabouts or all-way STOP-controlled intersections along the facility.
- No on-street parking and no restrictive median.
- Coordinated, semi-actuated traffic signals, with some progression provided in the analysis direction (i.e., arrival type 4).
- Protected left-turn phases provided for the major street, and the weighted average g/C ratio (i.e., ratio of effective green time for the through movement in the analysis direction to the cycle length) = 0.45.
- Exclusive left-turn lanes with adequate queue storage are provided at traffic signals and no exclusive right-turn lanes are provided.
- At each traffic signal, 10% of traffic on the major street turns left and 10% turns right.
- Peak hour factor = 1.00 and base saturation flow rate = 1,900 pc/h/ln.
- The facility is exactly two segments long with exactly three signals, so a facility with 1,320 feet (0.25 mile) between signals is 2,640 feet long.
- Two access points between each traffic signal, regardless of signal spacing. Each access point has two lanes in and two lanes out, with a peak hour volume of 180 veh/h turning into each driveway and 180 veh/h turning out of each driveway.
- *K*-factor (ratio of weekday peak hour two-way traffic to AADT) = 0.09 and *D*-factor (proportion of peak hour traffic in the peak direction) = 0.60. For other *K*- and *D*- values, multiply AADTs by the assumed factor values (i.e., 0.09 and 0.60) and divide by the desired values.

Exhibit 47. Signal approach through movement capacities per lane.

Saturation Flow Rate (veh/h/ln)	Through Movement *g/C*		
	0.40	0.45	0.50
1,500	600	675	750
1,600	640	720	800
1,700	680	765	850
1,800	720	810	900
1,900	760	855	950

Notes: Entries are through vehicles per hour per through lane.

If exclusive turn lanes are present on the signal approach, then the total approach volumes used to screen for capacity problems should be reduced by the number of turning vehicles. A default value of 20% turns (10% lefts, 10% rights) may be used if both exclusive left- and right-turn lanes are present.

Saturation flow rates, in vehicles per hour of green per lane, are effective rates after adjustments for heavy vehicles, turns, peak hour factor, and other factors affecting saturation flow.

g/C = ratio of effective green time to traffic signal cycle length.

Sensitivity of Predicted Urban Street Speeds

Analysts should be aware of the following sensitivities of the HCM urban street estimation method:

- The HCM-predicted average speeds under low-flow conditions may be higher or lower than the posted speed limit, depending on the posted speed limit and the signal spacing.
- For through movement v/c ratios below 1.00, average speeds are much more sensitive to changes in v/c ratios than are freeways and highways. For freeways and multilane highways, the speed–flow curve is relatively flat until the v/c ratio at the bottleneck exceeds 1.00. For urban streets, the speed–flow curve drops comparatively rapidly with increasing v/c ratios, even when the v/c ratio is significantly below 1.00.
- As demand increases on an urban street (but is still below a v/c of 1.00), there comes a point in the HCM method where the additional through traffic on the urban street at the unsignalized driveways (access points) can be significantly delayed by the driveways, thereby significantly reducing the predicted speed.
- The HCM-estimated speed ceases to be sensitive to increases in demand once the v/c ratios on the upstream signal approaches feeding the downstream link reach 1.00. Further increases in demand are stored on the upstream signal approaches. The HCM speed estimation method for urban streets does not currently add in the delay to vehicles stored on the upstream signal approaches. For this reason, the HCM arterial method cannot be currently relied upon for speed prediction when the demands on the upstream signal approaches exceed a v/c of 1.00.

5. Employing the HCM Method with Defaults

The HCM facility analysis method is described in HCM Chapter 16 and draws from the segment analysis method in HCM Chapter 18. Urban street reliability analysis is described in HCM Chapter 17. Exhibit 48 lists the data needed to evaluate the full range of performance measures for planning-level urban street analysis. Individual performance measures may require only a subset of these inputs.

The estimation of free-flow speeds using the HCM Chapter 17 method requires information on the posted speed limit, median type, presence of a curb, the number of access points per mile, the number of through lanes, and signal spacing.

Urban street capacity, which is determined by the through capacities of the controlled intersections, requires intersection control data, intersection demands, intersection lane geometry, and the analysis period length.

Average speed, motorized vehicle LOS, and multimodal LOS require the intersection capacities and free-flow speed plus additional data on segment lengths, demands, and lanes.

Queues are estimated based on the intersection control, demand, and geometric data.

Reliability analysis requires all the data required to estimate average speed, plus additional information on demand variability, incident frequencies and duration, weather, and work zones.

6. Simplified HCM Segment Analysis Method

This simplified urban street segment analysis method assumes that the segments between intersections have no access points between the intersection boundaries and that there are no turning movements at the intersection. All intersections are assumed to be signalized. The method does not consider the effects of a median. Exhibit 49 provides a flow diagram showing the analysis steps for the method.

Exhibit 48. Required data for urban street analysis with the HCM.

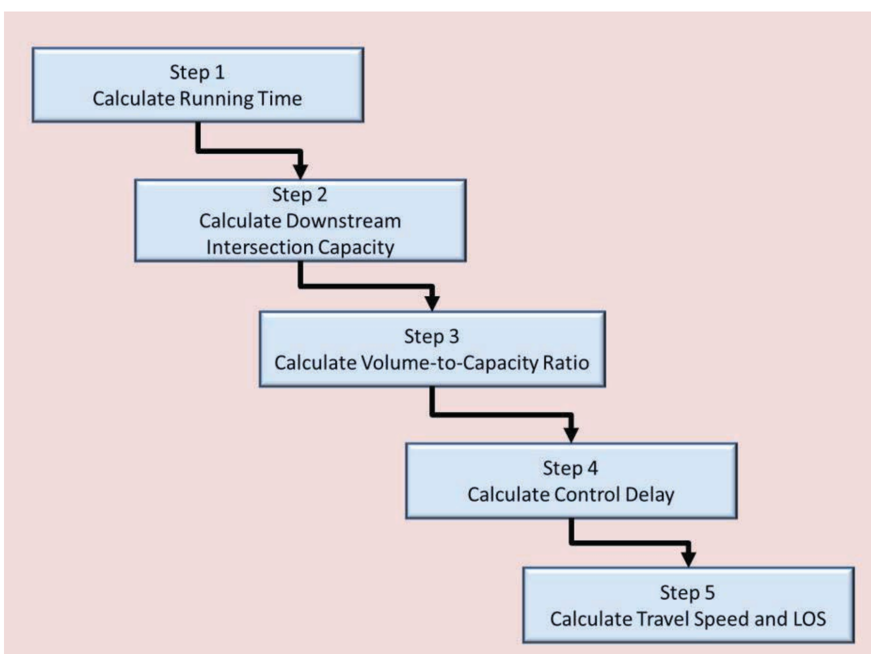
Input Data (units)	Performance Measures							Default Values
	FFS	Cap	Spd	LOS	MMLOS	Que	Rel	
Posted speed limit (mph)	•		•	•	•		•	Must be provided
Median type	•		•	•	•		•	Must be provided
Curb presence	•		•	•	•		•	Must be provided
Access points per mile	•		•	•	•		•	HCM Exhibit 18-7
Number of through lanes		•	•	•	•	•	•	Must be provided
Segment length (mi)			•	•	•	•	•	Must be provided
Directional demand (veh/h)			•	•	•	•	•	Must be provided
Percentage trucks (%)			•	•	•	•	•	3%
Intersection control data		•	•	•	•	•	•	See Section L, M, or N
Intersection demands		•	•	•	•	•	•	See Section L, M, or N
Intersection geometry		•	•	•	•	•	•	See Section L, M, or N
Analysis period length (h)		•	•	•	•	•	•	0.25 h
Seasonal demand variation							•	HCM Exhibits 17-5 through 17-7
Crash rate (crashes/yr)							•	Must be provided
Incident frequency, duration							•	HCM Exhibits 17-9 through 17-12
Local weather history							•	HCM Volume 4
Work zone probability							•	Optional

Notes: See appropriate sections in text for definitions of the required input data.

Data required for intersection analysis is not shown here. See Section L (signalized intersections), M (stop-controlled intersections), or N (roundabouts) as appropriate.

FFS = free-flow speed (default = speed limit plus 5 mph), Cap = capacity (veh/h/ln), Spd = average speed (mph), LOS = auto level of service, MMLOS = multimodal LOS (pedestrian, bicycle, transit), Que = queue (vehicles), and Rel = travel time reliability (multiple measures).

Exhibit 49. Simplified urban street segment analysis method steps.



Input Requirements

The method requires data for four input parameters:

1. The through movement volume along the segment v_m (veh/h),
2. The number of through lanes on the segment N_{TH},
3. The segment length L (ft), and
4. The posted speed limit S_{pl} (mph).

Default values are assumed for five other input parameters:

- Through movement saturation flow rate $s = 1{,}900$ veh/h/ln,
- Effective green ratio $g/C = 0.45$,
- Traffic signal cycle length $C = 120$ s,
- Progression quality along the segment = average, and
- Analysis period duration T = 0.25 h.

As a default, the cycle length is assumed to be 120 seconds and the g/C ratio is assumed to be 0.45. The latter value assumes that the green time is evenly divided between the north–south and east–west intersection approaches and that lost time accounts for ten percent of the cycle length. The analyst can and should override these defaults based on local knowledge (such as coordination plans). The quality of progression is assumed to be *average* (random arrivals), but the analyst can also select *good* (if there is some degree of coordination between the two signalized intersections) or *poor* (if there is poor coordination between the intersections).

Step 1: Calculate Running Time

The running time t_R is calculated as follows:

$$t_R = \frac{3{,}600 \times L}{5{,}280 \times (S_{pl} + UserAdj)} \quad \text{Equation 58}$$

where

t_R = running time excluding intersection delays (s),
S_{pl} = posted speed limit (mph),
$UserAdj$ = user-selected adjustment (mph) to reflect the difference between the facility's posted speed limit and the free-flow speed (default = 5 mph), and
L = segment length (ft).

The default value for *UserAdj* assumes that the facility's free-flow speed between controlled intersections is 5 mph greater than the posted speed limit. The analyst may wish to choose an alternative assumption to better reflect local conditions.

Step 2: Calculate the Capacity of the Downstream Intersection

The capacity of the downstream intersection is calculated as follows:

$$c = g/C \times N_{TH} \times s \quad \text{Equation 59}$$

where

c = capacity of the downstream intersection (veh/h),
g/C = effective green ratio for the through movement (default = 0.45) (unitless),

N_{TH} = number of through lanes, and
s = saturation flow rate for the through movement (veh/h/ln).

Step 3: Calculate the Volume-to-Capacity Ratio

The volume-to-capacity ratio for the through movement X is calculated as follows:

$$X = \frac{v_m}{c}$$ Equation 60

where

X = volume-to-capacity ratio for the through movement (unitless),
v_m = through movement volume along the segment (veh/h), and
c = capacity of the downstream intersection (veh/h).

Step 4: Calculate the Control Delay

The control delay d in seconds per vehicle is determined either from the signalized intersection planning method (see Sections L5) or calculated as described herein.

The uniform delay d_1 is calculated using Equation 61.

$$d_1 = \frac{0.5C(1 - g/C)^2}{1 - [\min(1, X)(g/C)]}$$ Equation 61

where

d_1 = uniform delay for through vehicles (s/veh),
C = traffic signal cycle length (s),
g/C = effective green ratio for the through movement (unitless), and
X = volume-to-capacity ratio for the through movement (unitless).

The incremental delay d_2 is calculated as follows:

$$d_2 = 225\left[(X-1) + \sqrt{(X-1)^2 + \frac{16X}{cN_{TH}}}\right]$$ Equation 62

where

d_2 = incremental delay for through vehicles (s/veh),
X = volume-to-capacity ratio for the through movement (unitless),
c = capacity of the downstream intersection (veh/h), and
N_{TH} = number of through lanes.

The average control delay d for through vehicles is calculated using Equation 63.

$$d = d_1 PF + d_2$$ Equation 63

where

d = average control delay for through vehicles (s/veh),
d_1 = uniform delay for through vehicles (s/veh),
PF = progression factor reflecting the quality of signal progression (unitless) from Exhibit 50, and
d_2 = incremental delay for through vehicles (s/veh).

Exhibit 50. Progression factor.

Progression Quality	Progression Factor (*PF*)
Good (some degree of coordination between the two signalized intersections)	0.70
Average (random arrivals)	1.00
Poor (poor coordination between the intersections)	1.25

Step 5: Calculate the Average Travel Speed and Determine Level of Service

The average travel time on the segment T_T is calculated using Equation 64.

$$T_T = t_R + d \qquad \text{Equation 64}$$

where

T_T = average though movement travel time (s),
t_R = running time (s), and
d = average control delay for through vehicles (s/veh).

The average travel speed on the segment $S_{T,seg}$ is calculated using Equation 65.

$$S_{T,seg} = \frac{3,600 \times L}{5,280 \times T_T} \qquad \text{Equation 65}$$

where

$S_{T,Seg}$ = average travel speed for the through movement (mph),
L = segment length (ft), and
T_T = average though movement travel time (s).

A spreadsheet-based computational engine has been developed for use in computing each of the data elements. Worksheets for completing the calculations are provided in Exhibit 51.

Once the average speed is estimated, the level of service is looked up in Exhibit 52.

Extension to Oversaturated Conditions

Cases in which demand exceeds capacity are common in urban street networks, particularly when considering future planning scenarios. This condition is considered to be sustained when demand exceeds capacity over an entire analysis period, not just for one or two signal cycles. The condition is illustrated in Exhibit 53, where the arrival volume v_1 during the analysis period t_1 exceeds the capacity c for the downstream intersection approach. During the second analysis period t_2 the arrival volume v_2 is sufficiently low such that the queue that formed during t_1 clears before the end of t_2. The area between the demand line and the capacity line represents the overflow delay experienced by all vehicles arriving during these two analysis periods. Each of the two analysis periods shown in Exhibit 53 represents a number of signal cycles.

In contrast, the delay resulting from the failure of an individual cycle ("the occasional overflow queue at the end of the green interval") is accounted for by the d_2 term of the delay equation for signalized intersections and urban street segments. This condition is illustrated in Exhibit 54 where a queue exists for two cycles, but clears in the third cycle. The non-zero slope of the departure

Exhibit 51. Simplified urban street method worksheets.

Simplified Urban Street Method, Input Data Worksheet		
Input Data	**Direction 1 (EB/NB)**	**Direction 2 (WB/SB)**
Through movement volume v_m (veh/h)		
Number of through lanes N_{TH}		
Segment length L (ft)		
Posted speed limit S_{pl} (mph)		
Through move saturation flow rate s (veh/h/ln) (default = 1,900)		
Effective green ratio g/C (default = 0.45)		
Cycle length C (s) (default = 120)		
Progression quality (good, average, poor) (default = average)		
Analysis period T (h) (default = 0.25)		
Simplified Urban Street Method, Calculation Worksheet		
Step 1. Running Time	**Direction 1 (EB/NB)**	**Direction 2 (WB/SB)**
Running time (s): $t_R = \frac{3{,}600 \times L}{5{,}280 \times (S_{pl} + UserAdj)}$		
Step 2. Capacity	**Direction 1 (EB/NB)**	**Direction 2 (WB/SB)**
Capacity (veh/h): $c = g/C \times N_{TH} \times s$		
Step 3. Volume-to-Capacity Ratio	**Direction 1 (EB/NB)**	**Direction 2 (WB/SB)**
Volume-to-capacity ratio: $X = \frac{v_m}{c}$		
Step 4. Control Delay	**Direction 1 (EB/NB)**	**Direction 2 (WB/SB)**
Uniform delay (s): $d_1 = \frac{0.5C(1-g/C)^2}{1-[\min(1,X)(g/C)]}$		
Incremental delay (s): $d_2 = 225\left[(X-1) + \sqrt{(X-1)^2 + \frac{16X}{cN_{TH}}}\right]$		
Progression factor PF: 0.70 (good), 1.00 (average), 1.25 (poor)		
Control delay (s): $d = d_1 PF + d_2$		
Step 5. Average Travel Speed	**Direction 1 (EB/NB)**	**Direction 2 (WB/SB)**
Travel time (s): $T_T = t_R + d$		
Travel speed (mph): $S_{T,seg} = \frac{3{,}600 \times L}{5{,}280 \times T_T}$		

Note: EB = eastbound, NB = northbound, WB = westbound, SB = southbound.

Exhibit 52. Urban street LOS average speed thresholds.

	Base Free-Flow Speed (mph)						
LOS	**55**	**50**	**45**	**40**	**35**	**30**	**25**
A	>44	>40	>36	>32	>28	>24	>20
B	>37	>34	>30	>27	>23	>20	>17
C	>28	>25	>23	>20	>18	>15	>13
D	>22	>20	>18	>16	>14	>12	>10
E	>17	>15	>14	>12	>11	>9	>8
F	≤17	≤15	≤14	≤12	≤11	≤9	≤8
	or any v/c > 1.0						

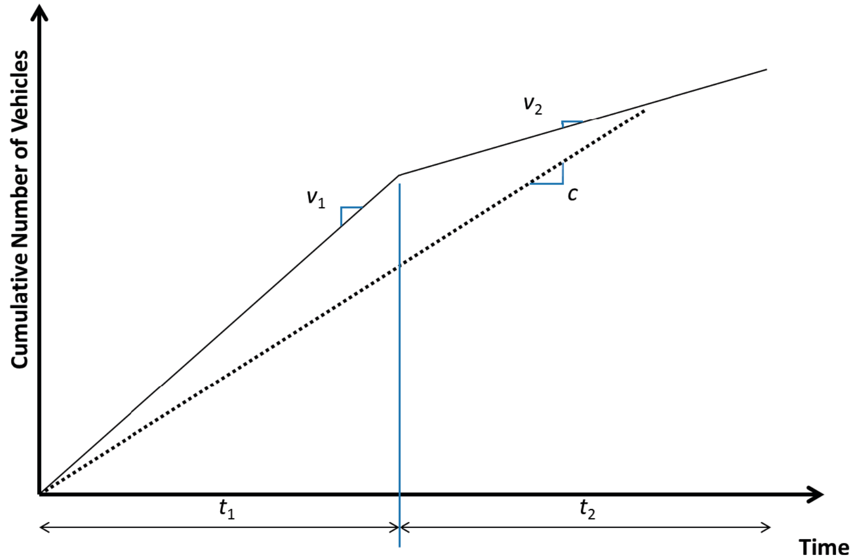
Source: HCM (2016), Exhibit 16-3.

Notes: Entries are minimum average travel speeds (mph) for a given LOS.

The base free-flow speed is estimated as described in HCM Chapter 18, page 18-28, or can be approximated by adding 5 mph (or other appropriate adjustment) to the posted speed limit.

v/c = volume-to-capacity ratio for the through movement in the analysis direction at the boundary intersection.

Exhibit 53. Overflow delay when demand exceeds capacity over the analysis period.

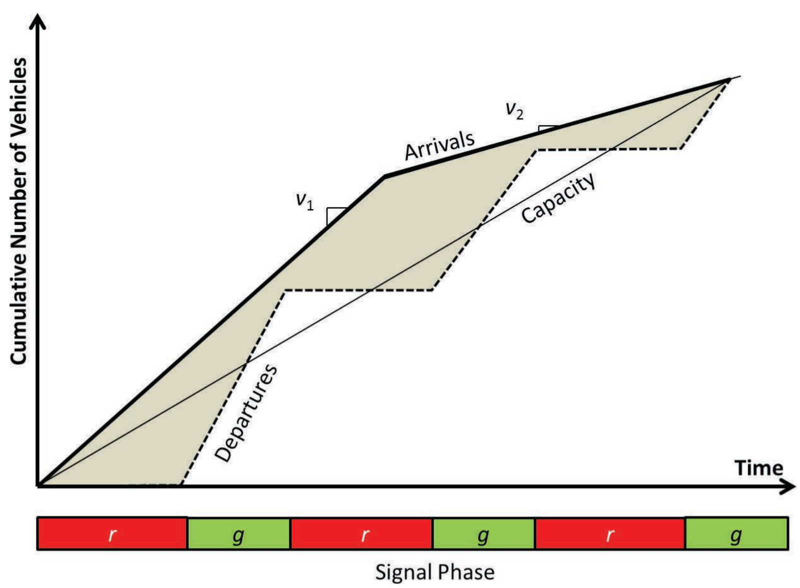


line during the green interval is equal to the saturation flow rate. The slope of the capacity line is the product of the saturation flow rate and the green ratio. The condition shown in Exhibit 54 is not considered to be sustained oversaturation and is therefore not addressed by the method described in this section.

Overview of the Method

The urban street segment planning method for oversaturated conditions predicts the overflow delay that results when the demand volume on an urban street segment exceeds its capacity. The method also predicts the v/c ratio for the first analysis period. The method considers only the

Exhibit 54. Delay resulting when demand is less than capacity over the analysis period.



through traffic on the segment. The method considers a queue that may exist at the beginning of the analysis period, the queue that exists at the end of the analysis period, and the time that it takes for this queue to clear during a second analysis period. The framework for determining the effect of oversaturation in the urban street segment is shown in Exhibit 55.

Limitations of the Method

The method does not consider mid-section movements or turning movements at the downstream intersection. The method does not consider the operational impacts of the queue spillback that result from the oversaturated conditions. The method can be used to analyze oversaturated conditions that result from demand exceeding capacity during several analysis periods. However, during the final analysis period, the demand must be such that the queue clears during this period.

Input Data Requirements

The input data requirements for the method include the following nine parameters:

- Arrival volumes v_1 and v_2 (veh/h) for the through movement at the downstream intersection during analysis period 1 (the period of oversaturation) and analysis period 2 (the period when the queue clears);
- Analysis period duration T (h);
- Segment length L (ft);
- Initial queue Q_0 (veh) existing at the beginning of analysis period 1 for the through movement at the downstream intersection;
- Number of through lanes in the segment N_{TH};
- Saturation flow rate s for the downstream signalized intersection (veh/h/ln); and
- Cycle length C (s) and effective green ratio g/C at the downstream signalized intersection.

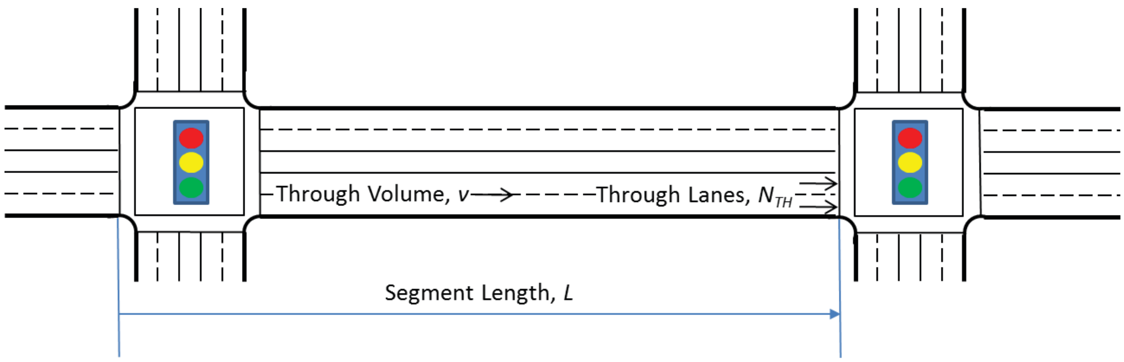
Default values are assumed for four of these parameters:

- $T = 0.25$ h,
- $s = 1{,}900$ veh/h/ln,
- $C = 120$ s, and
- $g/C = 0.45$.

Computational Steps

The planning method for urban street segments during periods of oversaturation is a simplified version of the operational analysis method for urban street segments for oversaturated

Exhibit 55. Oversaturated urban street segment planning method analysis framework.



conditions described in HCM Chapter 30. The method includes nine steps, shown in Exhibit 56 and described below.

Step 1: Calculate Queue Storage Capacity

The queue storage capacity Q_{cap} is the number of vehicles that can be stored in the segment, assuming an average vehicle length of 25 ft. The queue storage capacity is calculated as follows:

$$Q_{cap} = \frac{N_{TH} L}{25}$$ Equation 66

where

Q_{cap} = queue storage capacity (veh),
N_{TH} = number of though lanes in the subject direction, and
L = segment length (ft).

Step 2: Calculate Available Queue Storage

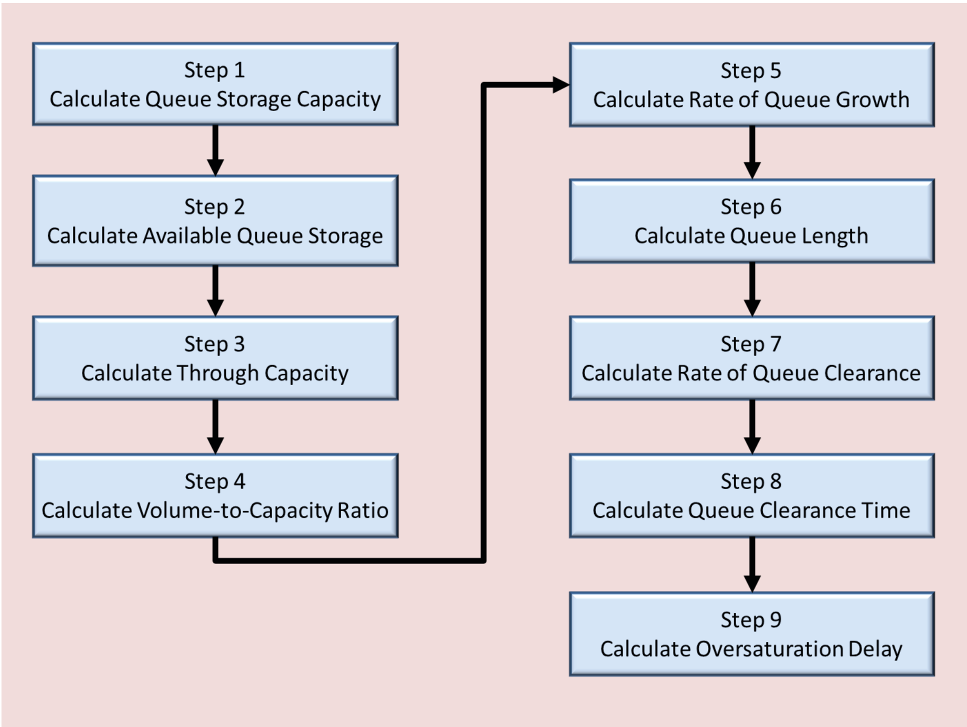
This step calculates the available queue storage Q_a in the segment during analysis period 1 after accounting for any initial queue Q_0 that is present at the beginning of the analysis period. The available queue storage is calculated using Equation 67.

$$Q_a = Q_{cap} - Q_0$$ Equation 67

where

Q_a = available queue storage capacity (veh) during analysis period 1,
Q_{cap} = queue storage capacity (veh), and
Q_0 = initial queue (veh) at the beginning of analysis period 1.

Exhibit 56. Urban street segment planning method, oversaturated conditions.



The available queue storage Q_a is compared to the estimated maximum queue (computed later) to identify queue overflow problems.

Step 3: Calculate Through Movement Capacity

Equation 68 is used to calculate the capacity of the through movement c_{TH} at the downstream signalized intersection.

$$c_{TH} = N_{TH} s \left(\frac{g}{C} \right)$$ Equation 68

where

c_{TH} = through movement capacity at the downstream signal (veh/h),
s = saturation flow rate for the through movement (veh/h),
g = effective green time for the through movement (s), and
C = traffic signal cycle length (s).

Step 4: Calculate Volume-to-Capacity Ratio

The volume-to-capacity ratio X for the segment during analysis period 1 is calculated as follows:

$$X = \frac{v_1}{c_{TH}}$$ Equation 69

where

X = volume-to-capacity ratio for the through movement (unitless),
v_1 = arrival volume (veh/h) during analysis period 1, and
c_{TH} = through movement capacity at the downstream signal (veh/h).

Step 5: Calculate Rate of Queue Growth

This step calculates the rate of queue growth r_{qg} during analysis period 1. If the through movement arrival volume v_1 is less than the capacity, no queue forms and this method is not needed. Equation 70 is used to calculate the rate of queue growth.

$$r_{qg} = v_1 - c_{TH} \geq 0.0$$ Equation 70

where

r_{qg} = rate of queue growth (veh/h) during analysis period 1,
v_1 = arrival volume (veh/h) during analysis period 1, and
c_{TH} = through movement capacity at the downstream signal (veh/h).

Step 6: Calculate Queue Length

The length of the queue Q_{max} at the end of analysis period 1 is determined as follows:

$$Q_{max} = r_{qg} t_1$$ Equation 71

where

Q_{max} = queue length (veh) at the end of analysis period 1,
r_{qg} = rate of queue growth (veh/h) during analysis period 1, and
t_1 = duration of analysis period 1 (h).

Step 7: Calculate Queue Clearance Rate

The rate of queue clearance r_{qc} during analysis period 2 is calculated as follows:

$$r_{qc} = c_{TH} - v_2 \quad \text{Equation 72}$$

where

r_{qc} = rate of queue clearance (veh/h) during analysis period 2,
c_{TH} = through movement capacity at the downstream signal (veh/h), and
v_2 = arrival volume (veh/h) during analysis period 2.

Step 8: Calculate Queue Clearance Time

The time for the queue to clear depends on the length of the queue at the end of analysis period 1, the arrival volume during analysis period 2, and the capacity of the through movement for the downstream intersection. If the queue does not clear before the end of analysis period 2, the volumes during subsequent analysis periods must be considered and the queue clearance time calculation must be modified to account for this result. The queue clearance time t_c is calculated using Equation 73.

$$t_c = \frac{r_{qg} t_1}{r_{qc}} = \frac{Q_{max}}{c_{TH} - v_2} \quad \text{Equation 73}$$

where

t_c = queue clearance time (h),
r_{qg} = rate of queue growth (veh/h) during analysis period 1,
t_1 = duration of analysis period 1 (h),
r_{qc} = rate of queue clearance (veh/h) during analysis period 2,
Q_{max} = queue length (veh) at the end of analysis period 1,
c_{TH} = through movement capacity at the downstream signal (veh/h), and
v_2 = arrival volume (veh/h) during analysis period 2.

Step 9: Calculate Oversaturated Delay

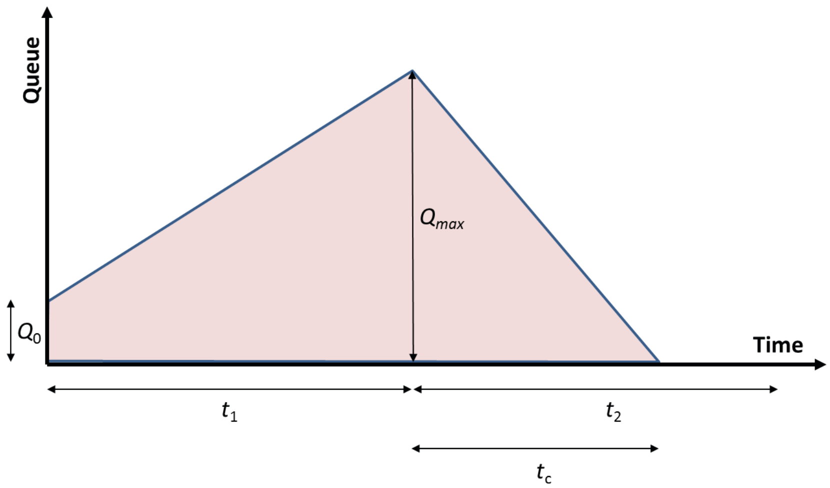
The final step calculates the delay resulting from oversaturation d_{sat}. Exhibit 57 shows the queue accumulation polygon for oversaturated conditions in which a queue grows during analysis period 1 and clears during analysis period 2. The area of the polygon that is formed by these conditions is the delay resulting from the oversaturated conditions. The average delay per vehicle is calculated as follows:

$$d_{sat} = \frac{0.5(Q_{max} - Q_0)t_1 + 0.5 t_c Q_{max}}{v_1 t_1 + v_2 t_c} \quad \text{Equation 74}$$

where

d_{sat} = delay resulting from oversaturation (s/veh),
Q_{max} = queue length at the end of analysis period 1 (veh),
Q_0 = initial queue (veh) at the beginning of analysis period 1,
t_1 = duration of analysis period 1 (h),
t_c = queue clearance time (h),
v_1 = arrival volume (veh/h) during analysis period 1, and
v_2 = arrival volume (veh/h) during analysis period 2.

Exhibit 57. Queue accumulation polygon for oversaturated conditions.



Computational Tools

A spreadsheet has been developed for use in calculating each of the data elements. A worksheet for completing the calculations is provided as Exhibit 58.

7. Reliability Analysis

HCM Chapter 17 describes a method for estimating urban street reliability that is sensitive to demand variations, weather, incidents, and work zones. The Florida DOT has also developed a method for estimating reliability for urban streets (Elefteriadou et al. 2013). Both methods are data- and computationally intensive, requiring custom software to implement. As such, neither method is readily adaptable to a planning and preliminary application that could be programmed in a simple, static spreadsheet. Analysts wishing to perform a reliability analysis of urban streets should consult these sources.

8. Multimodal LOS

Bicycle, Pedestrian, and Transit LOS

The HCM provides methods for evaluating bicycle, pedestrian, and transit LOS on urban streets, which are described in Section O4.

Truck LOS

The HCM does not provide a truck LOS method. However, the truck LOS estimation procedure described in Section P can be used to estimate truck LOS for urban streets.

9. Example

Case Study 2 (Section U) provides an example application of the screening and simplified analysis methods described in this section.

Exhibit 58. Oversaturated urban street segment planning method worksheet.

Oversaturated Urban Street Segment Planning Method, Input Data Worksheet	
Input Data	
Arrival volume, time period 1 v_1 (veh/h)	
Arrival volume, time period 2 v_2 (veh/h)	
Analysis period duration T (h)	
Segment length L (ft)	
Initial queue Q_0 (veh)	
Number of through lanes N_{TH}	
Through movement saturation flow rate s (veh/h/ln)	
Effective green ratio g/C	
Cycle length C (s)	
Oversaturated Urban Street Segment Planning Method, Calculation Worksheet	
Step 1: Queue Storage Capacity (veh)	
$Q_{cap} = \frac{N_{TH}L}{25}$	
Step 2: Available Queue Storage (veh)	
$Q_a = Q_{cap} - Q_0$	
Step 3: Capacity of Through Movement (veh/h)	
$c_{TH} = N_{TH}s\left(\frac{g}{C}\right)$	
Step 4: Volume-to-Capacity Ratio	
$X = \frac{v_1}{c_{TH}}$	
Step 5: Rate of Queue Growth (veh/h)	
$r_{qg} = v_1 - c_{TH} \geq 0.0$	
Step 6: Length of Queue (veh)	
$Q_{max} = r_{qg}t_1$	
Step 7: Rate of Queue Clearance (veh/h)	
$r_{qc} = c_{TH} - v_2$	
Step 8: Time of Queue Clearance (h)	
$t_c = \frac{r_{qg}t_1}{r_{qc}} = \frac{Q_{max}}{c_{TH} - v_2}$	
Step 9: Oversaturation Delay (s)	
$d_{sat} = \frac{0.5(Q_{max} - Q_0)t_1 + 0.5t_cQ_{max}}{v_1t_1 + v_2t_c}$	

10. References

Elefteriadou, L., Z. Li, and L. Jin. *Modeling, Implementation, and Validation of Arterial Travel Time Reliability.* Final Report, FDOT Contract BDK77 977-20, University of Florida, Gainesville, Nov. 30, 2013.

Highway Capacity Manual: A Guide to Multimodal Mobility Analysis. 6th ed. Transportation Research Board, Washington, D.C., 2016.

O. Pedestrians, Bicyclists, and Public Transit

1. Overview

In addition to providing performance measures and computational methods for the motorized vehicle mode, the HCM also provides a variety of measures for pedestrians and bicycles on various types of on- and off-street facilities. The HCM also provides a transit LOS measure for evaluating on-street public transit service in a multimodal context. A sister publication, the *Transit Capacity and Quality of Service Manual* (TCQSM) (Kittelson & Associates et al. 2013), provides a variety of performance measures, computational methods, and spreadsheet tools to evaluate the capacity, speed, reliability, and quality of service of on- and off-street transit service.

The HCM's pedestrian and bicycle performance measures focus on (1) the impacts of other facility users on pedestrians and bicyclists and (2) facility design and operation features under the control of a transportation agency. However, some analyses may also be interested in the effects of urban design on pedestrians' and bicyclists' potential comfort and enjoyment while using a facility. In those cases, additional measures, such as the Walkability Index (Hall 2010) or the Bicycle Environment Quality Index (San Francisco Department of Public Health 2009), could be appropriate.

This section is organized by HCM system element, providing guidance on applying the HCM and TCQSM's pedestrian, bicycle, and transit methods to a planning and preliminary engineering study. As research has not yet been conducted to quantify the pedestrian and bicycle experience for all types of HCM system elements, not every mode is addressed in every subsection below.

2. Freeways

Pedestrians and Bicycles

In most cases, pedestrians and bicycles are prohibited on freeways; therefore, the operations and quality of service of these modes on freeways is not assessed. In some cases, a multiple-use path is provided within the freeway facility, with a barrier separating non-motorized and motorized traffic. In these situations, the pedestrian and bicycle facility should be analyzed as an off-street pathway (see Section O8). In situations where bicycles are allowed on freeway shoulders, the HCM provides no guidance on evaluating performance. It is not recommended to use the HCM's multilane highway method for bicycles to evaluate bicycle quality of service on freeway shoulders, as the method was developed from urban street and suburban multilane highway data and has not been calibrated to freeway environments.

Transit

Buses operating on freeways in level terrain will generally operate at the same speed as other vehicular traffic, although buses designed to primarily operate on urban streets may not have the power to travel at higher freeway speeds (e.g., over 55 mph). In addition, buses designed to primarily operate on urban streets may have poor performance on steep grades—particularly when fully loaded with passengers—and are recommended to be evaluated as a truck in these cases. Buses designed for freeway travel (i.e., motor coaches designed for long-distance trips) generally do not experience these issues.

When bus routes stop along a freeway facility (e.g., at a stop or station in the freeway median or within a freeway interchange), the TCQSM can be consulted for guidance on estimating the delay associated with each stop. The TCQSM can also be consulted for performance measures for rail transit operating within a freeway right-of-way.

In general, buses operating on freeway facilities will experience the same conditions as other vehicles in the general purpose or managed lanes (where applicable) and could be assigned the same LOS as for motorized vehicle traffic generally. Alternatively, where buses stop along the freeway facility to serve passengers, the transit LOS measure for urban streets described in Section O4 could be applied to the stops along the freeway facility, with appropriate adjustments to the assumed average passenger trip length and baseline travel time rate, and considering the pedestrian LOS of the access route to the stop.

3. Multilane and Two-Lane Highways

Pedestrians

When pedestrian facilities exist along a multilane highway (e.g., a sidewalk along a multilane highway in a suburban area), the facility can be analyzed as an urban street pedestrian facility (see Section O4). However, if the pedestrian facility is separated from a multilane or two-lane highway by a barrier, or is generally located more than 35 feet away from the travel lanes, it should be analyzed as an off-street facility (see Section O8). Lower-speed two-lane highways (posted speeds of 45 mph or less) can be evaluated using the urban street pedestrian method (Section O4), whether or not a sidewalk exists. However, the HCM's urban street pedestrian method is not calibrated for, and not recommended for use with, higher speed two-lane highways or multilane highways lacking sidewalks or sidepaths.

Bicycles

HCM Chapter 15 provides a method for evaluating bicyclist perceptions of quality of service along multilane and two-lane highways. The method generates a bicycle LOS score, which can be translated into a bicycle LOS letter or used on its own. Exhibit 97 lists the required data for this method and provides suggested default values.

Of the inputs listed in Exhibit 97, the LOS result is highly sensitive to shoulder width and heavy vehicle percentage and is somewhat sensitive to lane width and pavement condition (particularly very poor pavement).

The calculation of the bicycle LOS score is readily performed by hand, following the steps given in HCM Chapter 15, or can be easily set up in a spreadsheet.

Transit

The guidance presented above for transit operating on freeways (Section O2) is also applicable to multilane and two-lane highways.

Exhibit 97. Required data for multilane and two-lane highway bicycle analysis.

Input Data (units)	Default Value
Speed limit (mph)	Must be provided
Directional automobile demand (veh/h)*	Must be provided
Number of directional lanes	1 (two-lane highway), 2 (multilane highway)
Lane width (ft)*	12
Shoulder width (ft)*	6
Pavement condition rating (FHWA 5-point scale)	3.5 (good)
Percentage heavy vehicles (decimal)*	0.06**
Peak hour factor (decimal)*	0.88
Percent of segment with occupied on-highway parking	0.00

Notes: See HCM Chapter 15 for definitions of the required input data.
*Also used by the multilane or two-lane highway LOS methods for motorized vehicles.
**HCM Chapter 26 provides state-specific default values.

4. Urban Streets

Pedestrians

The HCM provides three pedestrian performance measures for urban street segments and facilities: space (reflecting the density of pedestrians on a sidewalk); speed (reflecting intersection delays); and a pedestrian LOS score (reflecting pedestrian comfort with the walking environment).

Exhibit 98 lists the data required for these measures and provides suggested default values.

Calculating the pedestrian LOS score requires a number of inputs. Most of these can be defaulted, and the ones that cannot be defaulted are used by the urban street motorized vehicle LOS method. Given that different pedestrian design standards are typically used for different combinations of roadway functional classifications and area types, it is recommended that analysts develop sets of default values covering the most common combinations for their study area, based on typical local conditions or design standards.

Pedestrian space and speed are sensitive to *effective sidewalk width,* representing the portion of the sidewalk that is actually used by pedestrians. Common effective width reductions are 1.5 feet adjacent to the curb and 2.0 feet adjacent to a building face; Exhibits 24-8 and 24-9 in HCM Chapter 24, Off-Street Pedestrian and Bicycle Facilities, provide effective width reductions for many other types of objects (e.g., street trees, street light poles, bus stop shelters, café tables). The effective width used for analysis purposes should be based on the narrowest point of the sidewalk from an effective width standpoint. As the types of objects that create effective width reductions will vary depending on the sidewalk design (e.g., use of landscape buffers, street tree presence) and the adjacent land uses, it is recommended that analysts develop a set of local effective width default values that cover the most common situations.

The HCM provides a pedestrian LOS score (and associated LOS letter) for urban street *links* (between signalized intersections), *segments* (a link plus the downstream intersection), and *facilities* (multiple contiguous segments) that relates to pedestrian perceptions of quality of service for each element. The pedestrian LOS score uses the same scale as related bicycle and transit LOS scores for urban streets, and a related urban street automobile traveler perception score, which allows for multimodal analyses in which the relative quality of service of each travel mode can be evaluated and compared. At present, at a facility level, the HCM methodology only evaluates signalized urban streets, and not streets with all-way stops, roundabouts, or interchanges. However, the link methodology can be used to evaluate pedestrian facilities along any urban street section between intersections.

Exhibit 98. Required data for urban street pedestrian analysis.

Input Data (units)	For SPC	For SPD	For PLOS	Default Value
Sidewalk width (ft)	•	•	•	12 (CBD), 5 (other)
Effective sidewalk width (ft)	•	•		8.5 (CBD), 3.5 (other)
Bi-directional pedestrian volume (ped/h)	•	•		Must be provided
Free-flow pedestrian speed (ft/s)	•	•	•	4.4
Segment length (ft)*		•	•	Must be provided
Signalized intersection delay walking along street (s)*		•	•	See Section O5 or use 12 (CBD), 30 (suburban)
Signalized intersection delay crossing street (s)*			•	See Section O5 or use 12 (CBD), 50 (suburban)
Outside lane width (ft)*			•	12
Bicycle lane width (ft)			•	0
Shoulder/parking lane width (ft)			•	1.5 (curb and gutter only) 8 (parking lane provided)
Percentage of segment with occupied on-street parking (decimal)			•	0.00 (no parking lane) 0.50 (parking lane provided)
Street trees or other barriers (yes/no)**			•	No
Landscape buffer width (ft)			•	0 (CBD), 6 (other)
Curb presence (yes/no)			•	Yes
Median type (divided/undivided)			•	Undivided
Number of travel lanes*			•	Must be provided
Directional vehicle volume (veh/h)*			•	Must be provided
Vehicle running speed (mph)*			•	See Section K6 or use the posted speed
Intersection pedestrian LOS score (unitless)			•	Calculated, see Section O5
Average distance to nearest signal (ft)			•	One-third the segment length

Notes: See HCM Chapter 18 for definitions of the required input data.
SPC = space, SPD = speed, PLOS = pedestrian level of service, CBD = central business district.
*Input data used by or calculation output from the HCM urban street motorized vehicle LOS method.
**Street trees, bollards, or other similar vertical barriers 3 feet or more tall, or a continuous barrier at least 3 feet tall.

As noted above, the pedestrian LOS methodology requires a number of input values, but most of these can be defaulted, particularly when local default values have been established for different combinations of roadway functional class and area type. The calculations can be performed by hand or (preferably when large numbers of segments will be evaluated) incorporated into a spreadsheet.

Equations in HCM Chapter 18, Urban Street Segments, are used to calculate a link LOS score. This score can be converted to a LOS letter and reported by itself, if the purpose of the analysis is to evaluate the pedestrian environment between intersections. Otherwise, the analyst can proceed to calculate a segment LOS score.

The segment LOS score combines the link LOS score and the signalized intersection LOS score (see Section O5), weighting the two scores by the relative amounts of time that pedestrians experience each element. It is calculated using HCM Equation 18-39. A roadway crossing difficulty factor also enters into this equation. This factor incorporates the lesser of the delays pedestrians experience when (1) trying to cross the street at an unsignalized midblock location (if legal), or (2) walking to the nearest traffic signal, crossing the street, and walking back on the other side of the street. The segment LOS score can be converted to a LOS letter and reported by itself (using HCM Exhibit 18-2), if the purpose of the analysis is to evaluate the pedestrian environment along a street segment, including intersection and street crossing effects. Otherwise, the analyst can proceed to calculate a facility LOS score.

The facility LOS score is calculated similarly to the segment LOS score, weighting the LOS scores of the individual links and signalized intersections that form the facility by the relative amounts of time that pedestrians experience each element. It is calculated using Equation 16-7 in HCM Chapter 16, Urban Street Facilities.

Planning Procedure for Estimating Pedestrian LOS

When pedestrian crowding and delays at signals are not a concern, then this procedure (adapted from the HCM segment method) can be used to quickly evaluate the pedestrian LOS for stretches of urban streets between signalized intersections. Signalized intersection effects, pedestrian density, and midblock roadway crossing difficulty are not considered in this procedure. For high pedestrian volume locations (over 1,000 pedestrians per hour), the HCM procedure for evaluating pedestrian space should be used.

The pedestrian segment LOS is determined by the perceived separation between pedestrians and vehicle traffic:

- Higher traffic speeds and higher traffic volumes reduce the perceived separation,
- Physical barriers and parked cars between motorized vehicle traffic and the pedestrians increase the perceived separation, and
- Sidewalks wider than 10 feet do not further increase the perceived separation.

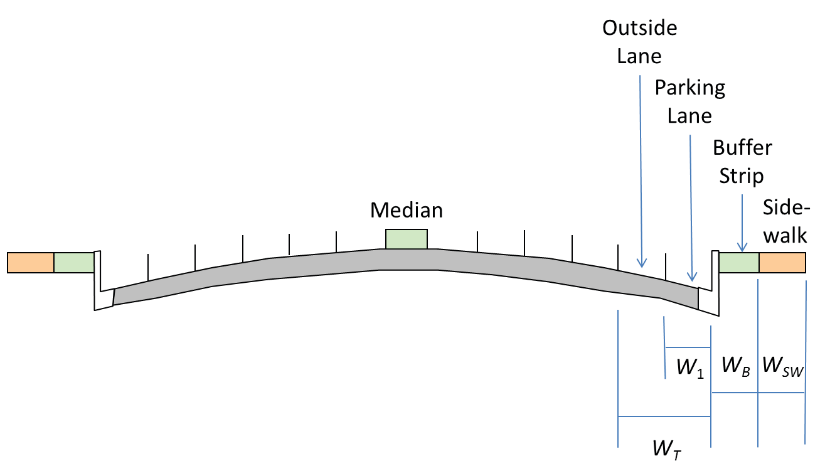
The segment pedestrian LOS is calculated as follows:

$$PLOS = -1.2276 \times \ln([f_{LV} \times W_T] + [0.5 \times W_1] + [0.5 \times \%OSP] + [f_B \times W_B] + [f_{SW} \times W_S]) + \frac{0.0091V}{4N} + (0.0004 \times SPD^2) + 6.0468 \qquad \text{Equation 148}$$

where

$PLOS$ = pedestrian level of service score for a segment (unitless),
ln = natural logarithm,
f_{LV} = low volume factor (unitless) = 1.00 if $V > 160$ veh/h and $(2.00 - 0.005V)$ otherwise,
W_T = distance from the inner edge of the outside lane to the curb (ft) (see Exhibit 99),
W_1 = distance from the outer edge of the outside lane to the curb (ft) (see Exhibit 99),

Exhibit 99. Measurement of widths for pedestrian LOS analysis.



$\%OSP$ = percent of segment with occupied on-street parking (percent),
f_B = buffer area coefficient (unitless) = 5.37 if a barrier is provided and 1.00 otherwise,
W_B = buffer width (ft), the distance between the curb and sidewalk (see Exhibit 99),
f_{SW} = sidewalk presence coefficient (unitless) = $6 - 0.3W_S$,
W_S = sidewalk width (ft) (see Exhibit 99), with a maximum allowed value of 10 ft,
V = directional volume of vehicles in the direction closest to pedestrians (veh/h),
N = number of through lanes of traffic in the direction closest to pedestrians, and
SPD = average vehicle speed between intersections (excluding stops) (mph).

Vertical objects at least 3 feet tall, such as street trees, bollards, or concrete barriers, that are sufficiently dense to be perceived as a barrier are treated as barriers for the purposes of determining the buffer area coefficient f_b.

The furnishings zone portion of a sidewalk (e.g., the area with street furniture, planters, and tree wells), such as often found in central business districts with wide sidewalks, is treated as part of the buffer strip width W_B. In these cases, the portion of the sidewalk allocated to pedestrian circulation would be used to determine the sidewalk width W_{SW}.

The pedestrian LOS method has not been designed or tested for application to rural highways and other roads where a sidewalk is not present and the traffic volumes are low but the speeds are high.

The PLOS score value is converted into a LOS letter using Exhibit 100.

Special Cases

This section gives guidance on the analysis of special cases.

Treatment of Sections with Significant Grades. The pedestrian LOS equations are designed for essentially flat grades (grades of under 2% of any length). For steeper grades, the analyst should consider applying an adjustment to the LOS estimation procedure to account for the negative impact of both upgrades and downgrades on pedestrian quality of service. This adjustment probably should be sensitive both to the steepness of the grade and its length. However, research available at the time this Guide was produced did not provide a basis for computing such an adjustment. The precise adjustment is left to the discretion of the analyst.

Pedestrian LOS and ADA Compliance. The Americans with Disabilities Act (ADA) sets various accessibility requirements for public facilities, including sidewalks on public streets. The United States Access Board (www.access-board.gov) has developed specific accessibility guidelines that apply to sidewalks and pedestrian paths.

Because pedestrian LOS is defined to reflect the average perceptions of the public, it is not designed to specifically reflect the perspectives of any particular subgroup of the public. Thus, the analyst

Exhibit 100. Level of service, pedestrians on urban streets.

PLOS Score	LOS
≤1.50	A
>1.50–2.50	B
>2.50–3.50	C
>3.50–4.50	D
>4.50–5.50	E
>5.50	F

Source: Adapted from HCM (2016), Exhibit 18-2.

should use caution if applying the pedestrian LOS methodology to facilities that are not ADA compliant. Pedestrian LOS is not designed to reflect ADA compliance or non-compliance, and therefore should not be considered a substitute for an ADA compliance assessment of a pedestrian facility.

Treatment of Street Sections with a Parallel Multiuse Path. Pedestrian LOS for urban streets applies to sidewalks and sidepaths located within 35 feet of the street (i.e., the distance within which research has demonstrated that vehicular traffic influences pedestrians' perceptions of quality of service). When a pedestrian pathway is located parallel to the street, but more than 35 feet from the street, it should be evaluated as an off-street pathway (see Section 08).

Treatment of Streets with Sidewalk on Only One Side. The pedestrian LOS analysis for both sides of the street proceeds normally. On one side, the sidewalk is evaluated. On the other side, the pedestrian LOS is evaluated using a sidewalk width of 0 feet.

Treatment of Discontinuous Sidewalks. Segments with relatively long gaps (over 100 feet) in the sidewalk should be split into sub-segments and the LOS for each evaluated separately.

The pedestrian LOS methodology is not designed to take into account the impact of short gaps in sidewalk (under 100 feet). Until such a methodology becomes available, short gaps may be neglected in the pedestrian LOS calculation. However, the analyst should report the fact that there are gaps in the sidewalk in addition to reporting the LOS grade.

Treatment of One-Way Traffic Streets. The pedestrian LOS analysis proceeds normally for both sides of the street, even when it is one-way. Note, however, that the lane and shoulder width for the left-hand lane are used for the sidewalk on the left-hand side of the street.

Treatment of Streets with Pedestrian Prohibitions or Sidewalk Closures. If pedestrians are prohibited from walking along the street by local ordinance or a permanent sidewalk closure, then the pedestrian LOS is F. No pedestrian LOS computations are performed.

Treatment of Streets with Frontage Roads. In some cases a jurisdiction will provide frontage roads to an urban street. There will usually be no sidewalks along the urban street, but there will be sidewalks along the outside edge of each frontage road.

If the analyst has information indicating that pedestrians walk along the urban street without the sidewalks, then the pedestrian LOS analysis should be performed for the urban street. If the analyst has information indicating that pedestrians walk exclusively along the frontage roads, then the pedestrian LOS analysis should be performed for the frontage roads.

Treatment of Pedestrian Overcrossings. The pedestrian LOS methodology is not designed to account for pedestrian bridges, either across the urban street or along the urban street.

Treatment of Railroad Crossings. The pedestrian LOS methodology is not designed to account for the impacts on pedestrian LOS of railroad crossings with frequent train traffic.

Treatment of Unpaved Paths/Sidewalks. The pedestrian LOS methodology is not designed to account for unpaved paths in the urban street right-of-way. The analyst should use local knowledge about the climate and the seasonal walkability of unpaved surfaces to determine whether an unpaved surface can be considered as almost as good as a paved sidewalk for the purpose of the pedestrian LOS computation. Otherwise the unpaved path should be considered the same as no sidewalk for the purpose of pedestrian LOS computation.

Treatment of Major Driveways. The HCM pedestrian LOS method and the planning procedure presented here are not designed to address the impacts of high-volume driveways on the pedestrian experience.

Bicycles

The HCM provides two bicycle performance measures for urban street segments and facilities: average travel speed (reflecting intersection delays) and a bicycle LOS score (reflecting bicyclist comfort with the bicycling environment). Exhibit 101 lists the data required for these measures and provides suggested default values.

As can be seen in Exhibit 101, calculating the bicycle LOS score requires a number of inputs. Most of these can be defaulted, and the ones that cannot be defaulted are used by the urban street motorized vehicle or pedestrian LOS methods. Given that different bicycle design standards are typically used for different combinations of roadway functional classifications and area types, it is recommended that analysts develop sets of default values covering the most common combinations for their study area, based on typical local conditions or design standards.

Bicycle LOS Score

The HCM provides a bicycle LOS score (and associated LOS letter) for urban street *links* (between signalized intersections), *segments* (a link plus the downstream intersection), and *facilities* (multiple contiguous segments) that relates to bicyclist perceptions of quality of service for each element. The bicycle LOS score uses the same scale as related pedestrian and transit LOS scores, and a related urban street automobile traveler perception score, which allows for multimodal analyses in which the relative quality of service of each travel mode can be evaluated and compared. At present, at a facility level, the HCM methodology only evaluates signalized urban streets and not streets with all-way stops, roundabouts, or interchanges. However, the link methodology can be used to evaluate bicycle facilities along any urban street section between intersections.

Exhibit 101. Required data for urban street bicycle analysis.

Input Data (units)	For SPD	For BLOS	Default Value
Bicycle running speed (mph)	•		12
Signalized intersection delay (s)	•	•	See Section O5 or use 10 (CBD), 22 (suburban)
Segment length (ft)*	•	•	Must be provided
Bicycle lane width (ft)**		•	5 (if provided)
Outside lane width (ft)**		•	12
Shoulder/parking lane width (ft)**		•	0 (curb and gutter only) 8 (parking lane provided)
Percentage of segment with occupied on-street parking (percent)**		•	0 (no parking lane) 50 (parking lane provided)
Pavement condition rating (1–5)		•	3.5 (good)
Curb presence (yes/no)**		•	Yes
Median type (divided/undivided)**		•	Undivided
Number of travel lanes*		•	Must be provided
Directional vehicle volume (veh/h)*		•	Must be provided
Vehicle running speed (mph)*		•	See Section K6 or use the posted speed
Percentage heavy vehicles (%)*		•	3%
Access points on the right side (points/mi)		•	17 (urban arterial), 10.5 (suburban arterial), 30.5 (urban collector), 24 (suburban collector)
Intersection bicycle LOS score (unitless)		•	Calculated, see Section O5

Notes: See HCM Chapter 18 for definitions of the required input data.
SPD = speed, BLOS = bicycle level of service, CBD = central business district.
*Input data used by or calculation output from the HCM urban street motorized vehicle LOS method.
**Input data used by the HCM urban street pedestrian LOS method.

As noted, the bicycle LOS methodology requires a number of input values, but most of these can be defaulted, particularly when local default values have been established for different combinations of roadway functional class and area type. The calculations can be performed by hand or (preferably when large numbers of segments will be evaluated) incorporated into a spreadsheet.

Equations 18-41 through 18-44 in HCM Chapter 18, Urban Street Segments, are used to calculate a link LOS score. This score can be converted to a LOS letter and reported by itself, if the purpose of the analysis is to evaluate the bicycling environment between intersections. Otherwise, the analyst can proceed to calculate a segment LOS score.

The segment LOS score combines the link LOS score and the signalized intersection LOS score (see Section O5), weighting the two scores by the relative amounts of time that bicyclists experience each element. It is calculated using HCM Equation 18-46. The number of access points per mile on the right side of the road (e.g., driveways, unsignalized cross-streets) also enters into this equation as a factor that causes discomfort to bicyclists. The segment LOS score can be converted to a LOS letter and reported by itself (using HCM Exhibit 18-3), if the purpose of the analysis is to evaluate the bicycling environment along a street segment, including intersection and access point effects. Otherwise, the analyst can proceed to calculate a facility LOS score.

The facility LOS score is calculated similarly to the segment LOS score, weighting the LOS scores of the individual links and signalized intersections that form the facility by the relative amounts of time that bicyclists experience each element. It is calculated using Equation 16-10 in HCM Chapter 16, Urban Street Facilities.

Planning Procedure for Evaluating Bicycle LOS

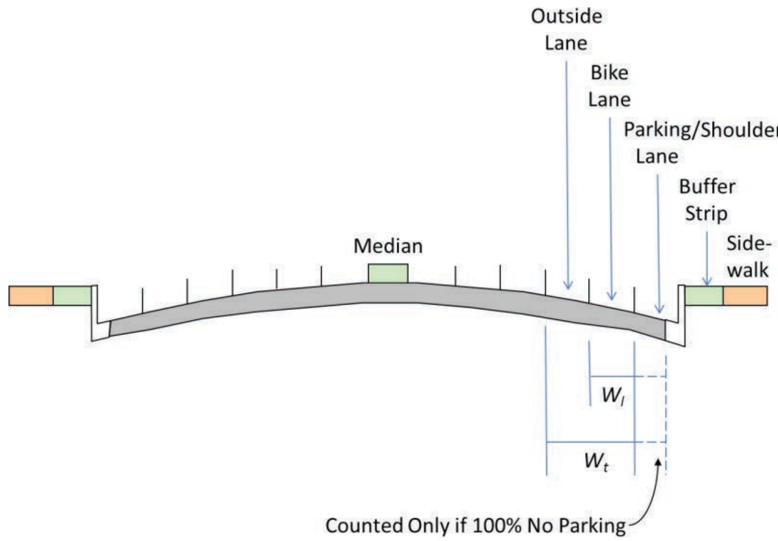
If bicyclist perceptions of signalized intersections are not a significant concern, the following planning method (adapting the HCM segment LOS method) can be used to quickly assess bicycle LOS for a street. The segment bicycle LOS is calculated according to the following equation:

$$BLOS = 0.507 \times \ln\left(\frac{V}{4N}\right) + \left(0.199 \times f_s \times [1 + 0.1038HV]^2\right) + \left(7.066 \times \left[\frac{1}{PC}\right]^2\right) - (0.005 \times W_e^2) + 0.760 \qquad \text{Equation 149}$$

where

$BLOS$ = bicycle level of service score for a segment (unitless),
ln = natural logarithm,
V = directional volume of vehicles in the direction closest to bicyclists (veh/h),
N = number of through lanes of traffic in the direction closest to bicyclists,
f_s = effective speed factor (unitless) = $(1.1199 \times \ln[S - 20] + 0.8103$,
HV = proportion of heavy vehicles in the motorized vehicle volume (%),
PC = pavement condition rating, using FHWA's five-point scale (1 = poor, 5 = excellent),
W_e = average effective width of the outside through lane (ft) = $W_v - (0.1 \times \%OSP)$ if $W_l < 4$ and $W_v + W_l - (0.2 \times \%OSP)$ otherwise, with a minimum value of 0,
W_v = effective width of the outside through lane as a function of traffic volume (ft) = W_T if $V > 160$ veh/h or the street is divided, and $W_T \times (2 - 0.005V)$ otherwise,
$\%OSP$ = percent of segment with occupied on-street parking (percent),
W_l = width of the bicycle lane and paved shoulder (ft); a parking lane can only be counted as shoulder if 0% occupied (see Exhibit 102) and the gutter width is not included, and

Exhibit 102. Widths used in bicycle LOS analysis.



W_T = width of the outside through lane, bicycle lane if present, and paved shoulder if present (ft); a parking lane can only be counted as shoulder if 0% occupied (see Exhibit 102) and the gutter width is not included.

If the traffic volume V is less than 200 veh/h, the value of HV must be less than or equal to 50% to avoid unrealistically poor LOS results for the combination of low volume and high percentage of heavy vehicles.

Note that this method does not account for bicycle-to-bicycle interference and should not be used where bicycle flows are expected to be high enough that significant bicycle-to-bicycle interference occurs.

The bicycle LOS score is converted into a letter using Exhibit 103.

Simplifications from the HCM

The HCM method for estimating bicycle level of service for urban streets is documented in HCM Chapters 16 (Urban Street Facilities), 18 (Urban Street Segments), and 19 (Signalized Intersections). This Guide makes the following simplifications to the HCM method to improve its utility for planning applications:

- Intersection analysis and facility analysis are excluded,
- Estimation of bicycle speeds and delays is excluded,

Exhibit 103. Level of service, bicycles on urban streets.

BLOS Score	LOS
≤1.50	A
>1.50–2.50	B
>2.50–3.50	C
>3.50–4.50	D
>4.50–5.50	E
>5.50	F

Source: Adapted from HCM (2016), Exhibit 18-3.

- Bicycle link LOS is used to characterize the segment (intersection plus link), and
- No provision is made for characterizing overall facility bicycle LOS.

For these features, the analyst must apply the HCM method as described in the HCM, applying default values as needed.

Special Cases

This section explains the evaluation of bicycle LOS for special cases.

Treatment of Sections with Significant Grades. The bicycle LOS equations are designed for essentially flat grades (grades of under 2% of any length). For steeper grades, the analyst should consider applying an adjustment to the LOS estimation procedure to account for the negative impact of both upgrades and downgrades on bicycle LOS. This adjustment probably should be sensitive both to the steepness of the grade and its length. However, research available at the time of production of this Guide did not provide a basis for computing such an adjustment. It is left to the discretion of the analyst.

Treatment of Sections with Parallel Multiuse Path. The bicycle LOS is computed separately for bicycles using the street and for bicycles using the parallel path. The bicycle LOS for the path is computed using the off-street path procedures described in Section O8.

Treatment of Bus Lanes, Bus Streets, and High Bus Volumes. The bicycle LOS methodology is not designed to adequately represent bicyclist perceptions of quality of service when they are operating on streets with frequent bus service with bus stops requiring bicyclists to move left to pass stopped buses. The analyst may choose to impose a weighting factor on the bus volume to better reflect the greater impact of the stopping buses on bicyclist LOS. The weighting factor would be at the analyst's discretion.

Treatment of Railroad Crossings and In-Street Tracks. The LOS methodology is not designed to account for the impacts of railroad crossings and the presence of tracks in the street (which may constitute a crash risk for bicyclists traveling parallel to the tracks) on bicycle LOS. The analyst may choose to adjust the pavement condition factor to a lower value to reflect the impacts of parallel in-pavement tracks and railroad crossings on bicycle LOS.

Transit

The HCM provides a transit LOS score for urban streets that reflects passenger comfort as they walk to a bus stop, wait for a bus, and ride on the bus. In addition, the TCQSM (Kittelson & Associates et al. 2013) provides the most up-to-date methods for calculating bus capacities and estimating average bus speeds on urban streets. Exhibit 104 lists the data required for these measures and suggests default values.

The HCM's transit LOS measure can be used to evaluate fixed-route transit service (e.g., bus, streetcar) that operates on the street and makes periodic stops to serve passengers. The TCQSM (Kittelson & Associates et al. 2013) can be used to evaluate the quality of service provided by other transit modes that travel within, above, or below the street right-of-way.

Bus Capacity

Bus capacity on an urban street is usually controlled by the capacity of the bus stops to accept and discharge buses. Bus capacity reflects the number of buses per hour that can serve the critical bus stop along a facility, at a desired level of reliability. The critical bus stop is typically the bus stop with the highest dwell time (i.e., serves the greatest number of passengers),

Exhibit 104. Required data for urban street transit analysis.

Input Data (units)	For CAP	For SPD	For TLOS	Default Value
Dwell time at critical stop (s)	•	•	○	60 (CBD, major transfer point), 30 (urban), 15 (suburban)
Average dwell time along facility (s)		•	○	45 (CBD), 20 (urban), 15 (suburban)
Coefficient of variation of dwell times (decimal)	•	•	○	0.60
Through traffic *g/C* ratio at critical stop (decimal)*	•	•	○	0.45 (CBD), 0.35 (other)
Curb lane *v/c* ratio at critical stop's intersection* (decimal)	•	•	○	Must be provided
Busiest stop location (online/offline)	•	•	○	Offline
Clearance time at critical stop (s)	•	•	○	10 (online stop, queue jump), 14 (far-side/midblock offline stop), 25 (near-side offline stop)
Number of loading areas at critical stop	•	•	○	1
Design failure rate (%)	•	•	○	10% (CBD), 2.5% (other), 25% (when calculating speed)
Bus frequency (bus/h)		•	•	Must be provided
Average bus stop spacing (stops/mi)		•	○	8 (CBD), 6 (urban), 4 (suburban)
Posted speed limit (mph)*		•	○	Must be provided
Average bus acceleration rate (ft/s^2)		•	○	3.4
Average bus deceleration rate (ft/s^2)		•	○	4.0
Bus lane type (4 categories)		•	○	Mixed traffic
Traffic signal progression (3 categories)		•	○	Typical
Average passenger load factor (p/seat)			•	Must be provided
Average excess wait time (min)			•	3
Percentage of stops with shelter (%)			•	25%
Percentage of stops with bench (%)			•	25%
Average passenger trip length (mi)			•	3.7
Pedestrian LOS score (decimal)**			•	Must be provided

Notes: See the TCQSM for definitions of the required input data.
CAP = capacity, SPD = speed, TLOS = transit level of service, CBD = central business district.
○ = required input if bus speeds are not already known (e.g., when evaluating future conditions).
*Input data used by or calculation output from the HCM urban street automobile LOS method.
**Calculation output from the HCM pedestrian LOS method.

but a lower-passenger-volume stop with short green times for buses or that experiences high right-turning traffic volumes can also be the critical stop. Bus capacity is calculated using Equation 150 and Equation 151, adapted from the TCQSM:

$$B = N_{el} f_{tb} \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Z c_v t_d} \quad \text{Equation 150}$$

$$f_{tb} = 1 - f_l\left(\frac{v_{cl}}{c_{cl}}\right) \quad \text{Equation 151}$$

where

B = bus capacity (bus/h),
N_{el} = number of effective loading areas at a bus stop, from Exhibit 105,
f_{tb} = traffic blockage adjustment factor (decimal),
3,600 = number of seconds in 1 hour,

Exhibit 105. Efficiency of multiple loading areas at bus stops.

Number of Physical Loading Areas	Bus Stop Type	
	Online	Offline
1	1.00	1.00
2	1.75	1.85
3	2.45	2.60
4	2.65	3.25
5	2.75	3.75

Source: Adapted from TCQSM (Kittelson & Associates et al., 2013), Exhibit 6-63.

Note: Values are numbers of effective loading areas for a given number of physical loading areas.

g/C = ratio of effective green time to total traffic signal cycle length (decimal),
t_c = clearance time (s),
t_d = average (mean) dwell time (s),
Z = standard normal variable corresponding to a desired failure rate, from Exhibit 106,
c_v = coefficient of variation of dwell times (decimal),
f_l = bus stop location factor (decimal), from Exhibit 107,
v_{cl} = curb lane traffic volume at intersection (veh/h), and
c_{cl} = curb lane capacity at intersection (veh/h).

When more than one bus can use the critical bus stop at a time (i.e., more than one *loading area* is provided), the bus stop's capacity will be greater than if only one loading area was provided. Exhibit 105 gives the number of effective loading areas for a given number of physical loading areas, for both online stops (buses stop in the travel lane) and offline stops (buses stop out of the travel lane).

Exhibit 106 provides values for *Z*, the standard normal variable, for different design *failure rates*—the percentage of time that a bus should arrive at a bus stop only to have to wait for other buses to finish serving their passengers before space opens up for the arriving bus to enter the stop. Capacity is maximized when a queue of buses exists to move into a bus stop as soon as other buses leave, but this situation causes significant bus delays and schedule reliability problems. Therefore, a lower design rate is normally used as an input for determining a design capacity, balancing capacity with operational reliability. However, the TCQSM's method for estimating

Exhibit 106. Values of *Z* associated with given failure rates.

Design Failure Rate	*Z*
1.0%	2.330
2.5%	1.960
5.0%	1.645
7.5%	1.440
10.0%	1.280
15.0%	1.040
20.0%	0.840
25.0%	0.675

Source: Adapted from TCQSM (Kittelson & Associates et al., 2013), Exhibit 6-56.

Exhibit 107. Bus stop location factor f_l values.

Bus Stop Location	Bus Freedom to Maneuver: Buses Restricted to Right Lane	Buses Can Use Adjacent Lane	Right Turns Prohibited or Dual Bus Lanes
Near-side of intersection	1.0	0.9	0.0
Middle of the block	0.9	0.7	0.0
Far-side of intersection	0.8	0.5	0.0

Source: Adapted from TCQSM (Kittelson & Associates et al., 2013), Exhibit 6-66.

bus speed is calibrated to maximum capacity and therefore uses a 25% (maximum practical) failure rate in its calculation.

The location of the critical bus stop relative to the nearest intersection and the ability of buses to avoid right-turning traffic also influence capacity. Exhibit 107 gives values for the bus stop location factor f_l used in Equation 151.

The curb lane capacity can be estimated using the procedure given in Section L4 or estimated from Exhibit 108, for a given combination of g/C ratio (effective green time divided by the traffic signal cycle length) and conflicting pedestrian volume for right turns.

Bus Speed

Two options are provided for planning-level estimates of bus speeds along urban streets:

1. If only a planning estimate of bus speeds is desired, then Option 1 can be followed. This option requires less data and is faster to calculate. It accounts for traffic and traffic signal delays in a generalized way.
2. If it is desired to estimate both automobile and bus speeds, then Option 2 can be followed. This option applies the same basic method used for automobiles, but makes adjustments to reflect (*a*) overlapping signal delay time and bus dwell time to serve passengers, (*b*) bus delays waiting to re-enter the traffic stream, and (*c*) bus congestion at bus stops when more than half of the facility's bus capacity is being used.

Option 1: Generalized Bus Speed Method. This option is based on the TCQSM's bus speed estimation method. In this option, bus speeds are calculated in four steps. First, an unimpeded

Exhibit 108. Approximate curb lane capacities.

Conflicting Pedestrian Volume (ped/h)	g/C Ratio for Curb Lane: 0.35	0.40	0.45	0.50	0.55	0.60
0	510	580	650	730	800	870
100	440	510	580	650	730	800
200	360	440	510	580	650	730
400	220	290	360	440	510	580
600	70	150	220	290	360	440
800	*	*	70	150	220	290
1,000	*	*	*	*	70	150

Source: HCM (2016), based on 1,450 × (g/C) × [1 − (pedestrian volume × (g/C) / 2,000)] with PHF = 1.

Note: *Vehicles can only turn at the end of green, assume one or two per traffic signal cycle. Values shown are for CBD locations, multiply by 1.1 for other locations.

bus travel time rate, in minutes per mile, is calculated for the condition in which a bus moves along a street without traffic or traffic signal delays, with the only source of delay being stops to serve passengers. Second, additional delays due to traffic and traffic signals are estimated. Third, the bus travel time rate is converted to an equivalent speed. Finally, the speed is reduced to reflect the effects of bus congestion.

Step 1: Unimpeded Bus Travel Time Rate. The unimpeded bus travel time rate is based on the posted speed, the number of stops per mile, the average dwell time per stop, and typical bus acceleration and deceleration rates. It is based on the delay experienced with each bus stop (deceleration, dwell time, and acceleration) and the time spent traveling at the bus's running speed (typically the posted speed) between stops. It is calculated using Equation 152 through Equation 157:

$$t_u = \frac{t_{rs} + N_s(t_{dt} + t_{acc} + t_{dec})}{60} \qquad \text{Equation 152}$$

$$t_{rs} = \frac{L_{rs}}{1.47 v_{run}} \qquad \text{Equation 153}$$

$$L_{rs} = 5{,}280 - N_s L_{ad} \geq 0 \qquad \text{Equation 154}$$

$$L_{ad} = 0.5 a t_{acc}^2 + 0.5 d t_{dec}^2 \qquad \text{Equation 155}$$

$$t_{acc} = \frac{1.47 v_{run}}{a} \qquad \text{Equation 156}$$

$$t_{dec} = \frac{1.47 v_{run}}{d} \qquad \text{Equation 157}$$

where

t_u = unimpeded running time rate (min/mi),
t_{rs} = time spent at running speed (s/mi),
N_s = average stop spacing (stops/mi),
t_{dt} = average dwell time of all stops within the section (s/stop),
t_{acc} = acceleration time per stop (s/stop),
t_{dec} = deceleration time per stop (s/stop),
60 = number of seconds per minute,
L_{rs} = distance traveled at running speed per mile (ft/mile),
1.47 = conversion factor (5,280 ft/mi/3,600 s/h),
v_{run} = bus running speed on the facility (typically the posted speed) (mph),
L_{ad} = distance traveled at less than running speed per stop (ft/stop),
a = average bus acceleration rate to running speed (ft/s^2), and
d = average bus deceleration rate from running speed (ft/s^2).

If the calculated length traveled at running speed in Equation 155 is less than zero, the bus cannot accelerate to the input running speed before it must begin decelerating to the next stop. In this case, the calculation sequence must be performed again with a lower running speed selected. The maximum speed that can be reached before the bus has to begin decelerating again can be computed using Equation 158 and Equation 159; however, the analyst may wish to choose a lower speed to reflect that bus drivers will typically cruise at a constant speed for some distance between stops, rather than decelerating immediately after accelerating.

$$t_{acc,dc} = \sqrt{\frac{5,280/N_s}{0.5a + \frac{a^2}{d}}}$$ Equation 158

$$v_{max} = \frac{a \times t_{acc,dc}}{1.47}$$ Equation 159

where

$t_{acc,dc}$ = distance-constrained acceleration time (s),
N_s = average stop spacing (stops/mi),
a = bus acceleration rate (ft/s^2),
d = bus deceleration rate (ft/s^2), and
v_{max} = maximum speed achievable between stops (mph).

Step 2: Additional Bus Travel Time Delays. Next, additional bus travel time delays t_l (in minutes per mile) are estimated directly from Exhibit 109, using the bus facility type, traffic signal progression quality, and area type as inputs.

Step 3: Base Bus Speed. The unimpeded bus travel time rate from Step 1 and the additional bus travel time delays from Step 2 are added together to obtain a base bus travel time rate t_r, which is then converted into a base bus speed S_b:

$$t_r = t_u + t_l$$ Equation 160

$$S_b = \frac{60}{t_r}$$ Equation 161

where

t_r = base bus running time rate (min/mi),
t_u = unimpeded running time rate (min/mi),
t_l = additional running time losses (min/mi),
60 = number of minutes in an hour, and
S_b = base bus speed (mph).

Step 4: Average Bus Speed. When at least half of a facility's maximum bus capacity is scheduled, bus congestion at bus stops reduces bus speeds below the base speed calculated in Step 3. The amount of this speed reduction is given by the bus–bus interference factor f_{bb}, which can be

Exhibit 109. Estimated bus running time losses on urban streets t_l (min/mi).

Condition	Bus Lane	Bus Lane, No Right Turns	Bus Lane With Right-Turn Delays	Bus Lanes Blocked by Traffic	Mixed Traffic Flow
CENTRAL BUSINESS DISTRICT					
Typical		1.2	2.0	2.5–3.0	3.0
Signals set for buses		0.6	1.4		
Signals more frequent than bus stops		1.75	2.75	3.25	3.75
ARTERIAL ROADWAYS OUTSIDE THE CBD					
Typical	0.7				1.0

Source: Adapted from TCQSM (Kittelson & Associates et al., 2013), Exhibit 6-73.

Exhibit 110. Bus–bus interference factor values.

Bus Volume-to-Maximum Capacity Ratio	Bus–Bus Interference Factor
<0.5	1.00
0.5	0.97
0.6	0.94
0.7	0.89
0.8	0.81
0.9	0.69
1.0	0.52
1.1	0.35

Source: TCQSM (Kittelson & Associates et al., 2013), Exhibit 6-75.

estimated from Exhibit 110. The input to this exhibit is the bus volume–to–maximum capacity ratio, where maximum bus capacity is estimated by using a 25% failure rate in Exhibit 106 when determining the value of the standard normal variable Z used in the bus capacity equation (Equation 150). Under typical conditions and if bus stops can only serve one bus at a time (i.e., one loading area per stop), at least 10–15 buses per hour need to be scheduled before bus speeds are affected.

Equation 162 is used to estimate the average bus speed on the urban street facility.

$$S_{bus} = S_b f_{bb} \qquad \text{Equation 162}$$

where

S_{bus} = average bus speed along facility (mph),
S_b = base bus speed (mph), and
f_{bb} = bus–bus interference factor (decimal).

Option 2: Modified Auto Speed Method. This option modifies the auto speed estimation method for urban street segments with signalized intersections (see Section K6) to reflect additional delays experienced by buses and to account for potentially overlapping traffic signal delay and dwell time delay.

The auto equation for estimating segment travel time is modified as follows for buses:

$$T_{i,bus} = \frac{5{,}280\ FFS}{3{,}600\ L_i} + d + d_{mb} + d_{bs} \qquad \text{Equation 163}$$

where

$T_{i,bus}$ = base bus travel time for segment i (s),
FFS = midblock free-flow speed (mph),
5,280 = number of feet per mile,
3,600 = number of seconds per hour,
L_i = distance from upstream intersection stop bar to downstream intersection stop bar for segment i (ft),
d = average control delay (s),
d_{mb} = midblock bottleneck delay (if any) (s), and
d_{bs} = total bus stop delay in the segment (s).

Total bus stop delay in the segment is calculated as follows:

$$d_{bs} = N_s(t_{dt} + t_{acc} + t_{dec} + t_{re}) \qquad \text{Equation 164}$$

where

d_{bs} = total bus stop delay in the segment (s),
N_s = number of bus stops in the segment (stops),
t_{dt} = average dwell time per stop (s/stop),
t_{acc} = bus acceleration time per stop (s/stop),
t_{dec} = bus deceleration time per stop (s/stop),
t_{re} = average re-entry delay per stop (s/stop) = t_{cl} – 10, and
t_{cl} = average clearance time per stop (s/stop).

When applying Equation 164, the number of bus stops in the segment includes all mid-block stops and any bus stop associated with the downstream intersection (even if far-side and technically located in the next segment). Similarly, any bus stop associated with the upstream intersection is excluded from the count of bus stops.

Average bus speed in the segment is calculated as follows:

$$S_{i,bus} = \frac{3{,}600\, L_i}{5{,}280\, T_{i,bus}} f_{bb} \qquad \text{Equation 165}$$

where

$S_{i,bus}$ = average bus speed for segment i including all delays (mph),
L_i = distance from upstream intersection stop bar to downstream intersection stop bar for segment i (ft),
$T_{i,bus}$ = base bus travel time for segment i (s), and
f_{bb} = bus–bus interference factor (decimal) from Exhibit 110.

Average facility bus speed is calculated as follows:

$$S_{bus} = \frac{3{,}600 \sum L_i}{5{,}280 \sum T_{i,bus}} \qquad \text{Equation 166}$$

where

S_{bus} = average bus speed along facility (mph),
L_i = distance from upstream intersection stop bar to downstream intersection stop bar for segment i (ft),
5,280 = number of feet per mile,
3,600 = number of seconds per hour,
$T_{i,bus}$ = base bus travel time for segment i (s).

Transit LOS Score

The HCM provides a transit LOS score (and associated LOS letter) for urban street *segments* (a link plus the downstream intersection) and *facilities* (multiple contiguous segments). The segment score relates to transit passengers' experiences walking to or from bus stops in the segment, waiting for buses at bus stops in the segment, and riding on buses within the segment. The transit LOS score uses the same scale as related pedestrian and bicycle LOS scores, and a related auto traveler perception score, allowing for multimodal analyses in which the relative quality of service of each travel mode can be evaluated and compared to each other. The calculations can be performed by hand or (preferably when large numbers of segments will be evaluated) incorporated into a spreadsheet.

HCM Equations 18-56 through 18-63 are used to calculate a link LOS score. This score can be converted to a LOS letter and reported by itself (using HCM Exhibit 18-3), if the purpose of the analysis is to evaluate transit conditions within a segment. Otherwise, a facility score is calculated by weighting the LOS scores of the individual segments that form the facility by the relative length of each segment. It is calculated using HCM Equation 16-13.

The transit LOS score is particularly sensitive to the bus frequency provided as an input, and is somewhat sensitive to the average bus speed and passenger load factor provided as inputs.

The HCM transit LOS score computations can be applied without change using defaults as needed. Alternatively, the transit LOS score computation steps shown below provide a few simplifications on the HCM procedure for planning applications.

$$TLOS = 6.0 - (1.50 \times s_{w-r}) + (0.15 \times PLOS) \qquad \text{Equation 167}$$

where

$TLOS$ = transit LOS score (unitless),
s_{w-r} = transit wait and ride score (unitless), and
$PLOS$ = pedestrian LOS score (unitless).

The computed transit LOS score is converted to an LOS letter using the equivalencies given in Exhibit 111.

Pedestrian LOS Estimation. The pedestrian LOS score for the urban street is estimated using the pedestrian LOS model described earlier in this section. Better PLOS values (i.e., LOS A-C) improve the TLOS score relative to what it would be if only transit factors were considered, while worse PLOS values (i.e., LOS D-F) reduce the TLOS score.

Transit Wait-Ride Score Estimation. The transit wait–ride score is a function of a bus headway factor f_h that reflects the multiplicative change in ridership along a route at a given headway, relative to the ridership at 60-minute headways, and a perceived travel time factor f_{ptt} that reflects the multiplicative change in ridership along a route at a given perceived travel time rate (*PTTR*), relative to the ridership at a baseline travel time rate (*BTTR*). The suggested baseline travel time rate is 4 min/mi (15 mph), except in the central business districts of metropolitan areas with over 5 million population, in which case it is 6 min/mi (10 mph). (These values can be adjusted by the analyst to reflect local passenger expectations of travel speeds.) Equation 168 shows the calculation of the transit wait-ride score.

Exhibit 111. Level of service, transit on urban streets.

TLOS Score	LOS
≤2.00	A
>2.00–2.75	B
>2.75–3.50	C
>3.50–4.25	D
>4.25–5.00	E
>5.00	F

Source: Adapted from HCM (2016), Exhibit 18-3.

$$s_{w-r} = f_h \times f_{ptt} \quad \text{Equation 168}$$

where

s_{w-r} = transit wait–ride score (unitless),
f_h = headway factor (unitless), and
f_{ptt} = perceived travel time factor (unitless).

The headway factor calculation incorporates assumed ridership elasticities that relate the percentage change in ridership to the percentage change in bus headways. Only the buses and bus routes that actually stop to pick up or drop off passengers within the study section of the street should be included in determining the average bus headway on the street. Express bus service without at least one bus stop on the street would be excluded. Equation 169 is used to calculate the headway factor.

$$f_h = 4 \times \exp(-0.0239h) \quad \text{Equation 169}$$

where

f_h = headway factor (unitless), and
h = average number of minutes between buses.

Perceived Travel Time Factor. The perceived travel time factor calculation incorporates assumed ridership elasticities that relate the percentage change in ridership to the percentage change in the perceived travel time rate. The perceived travel time rate, in turn, is a function of actual bus speeds (travel time rates) and factors that have been found to make the time spent waiting for or riding on the bus seem longer than the actual time. These factors include late bus arrivals; provision of shelters, benches, or both at bus stops; and crowding on board the bus. The perceived travel time factor is calculated using Equation 170 through Equation 172.

$$f_{ptt} = \frac{[(e-1)BTTR-(e+1)PTTR]}{[(e-1)PTTR-(e+1)BTTR]} \quad \text{Equation 170}$$

$$PTTR = (a_1 \times IVTTR) + (a_2 \times EWTR) - ATR \quad \text{Equation 171}$$

$$IVTTR = \frac{60}{S_{bus}} \quad \text{Equation 172}$$

where

f_{ptt} = perceived travel time factor (unitless),
e = ridership elasticity with respect to changes in the travel time rate (unitless), default = –0.40,
$BTTR$ = baseline travel time rate (min/mi), default = 6 for the central business district of metropolitan areas with populations of 5 million or greater, and 4 otherwise,
$PTTR$ = perceived travel time rate (min/mi),
a_1 = travel time perception coefficient for passenger load (unitless) = 1.00 when 80% or fewer of seats are occupied, 1.19 when all seats are occupied, and 1.42 with a standing load equal to 25% of the seating capacity; HCM Equation 18-59 can also be used,
$IVTTR$ = in-vehicle travel time rate (min/mi),
a_2 = travel time perception coefficient for excess wait time (unitless), default = 2.0,
$EWTR$ = excess wait time rate (min/mi) = (average wait for buses beyond the scheduled arrival time)/(average passenger trip length), default = 0.8, and

ATR = amenity time rate (min/mi) = (perceived wait time reduction due to bus stop amenities)/(average passenger trip length); default = 0.1 (bench provided), 0.3 (shelter only), and 0.4 (shelter and bench).

When field measurement of average bus speeds along the street is not feasible, the in-vehicle travel time rate can be estimated from the bus schedule as the travel time between timepoints on either side of the study section, divided by the on-street distance between the timepoints. The bus speed estimation procedure presented earlier can also be used.

The excess wait time is the average difference between the scheduled and actual arrival times for buses at the timepoint prior to the study section. For example, if buses arrive 3 minutes behind schedule on average at the timepoint, the excess wait time is 3 minutes. An early arrival at the timepoint without a corresponding early departure is treated as 0 minutes of excess wait time, but an early arrival combined with an early departure is counted as being one headway late.

Special Cases. This section gives guidance on the analysis of special cases.

Gaps in Transit Service. The portions of street where there is no transit service should be split into their own segments for the purpose of transit LOS analysis (if not already split for other reasons). The transit LOS should be set at F for these segments. The rest of the transit LOS analysis proceeds normally, with the overall transit LOS being a length-weighted average including the segments with no transit service.

No Through Transit Service for the Full Length of the Study Facility. The TLOS score is measured on a segment-by-segment basis and reflects in part actions that a roadway agency can take to improve bus speeds. It also reflects the amount of bus service provided within a given segment. It can be compared on a segment-by-segment basis to the LOS scores available for other travel modes, reflecting the quality of service provided within that segment. In this respect, it does not measure origin–destination service quality for transit passengers. Therefore, by default, no adjustment is made to the score if passengers would need to transfer from one route to another to make a complete trip through the study facility.

However, if the analyst is interested in measuring origin–destination service quality along a facility, one option would be to calculate the TLOS score as described above, but (1) double the assumed average trip length to reflect the linked (i.e., involving a transfer) trip, and (2) add a perceived transfer time rate equal to the average transfer time multiplied by a perceived waiting time factor (suggested default = 2) and divided by the average trip length.

Single-Direction Transit Service on a Two-Way Street. The direction of travel for which there is no transit service is assigned transit LOS F. The other direction of travel is evaluated normally.

Bus Lanes and Bus Streets. The methodologies are not specifically designed to handle bus streets and bus lanes, but with some judicious adjustments, they can be adapted to these special situations.

In the case of bus streets, the auto LOS is, by definition, LOS F (since autos cannot access this street). The transit, bicycle, and pedestrian LOS are computed normally, with transit vehicles being the only motorized vehicles on the street.

In the case of bus lanes, the auto, transit, bicycle, and pedestrian LOS analyses proceed normally. The only difference is that only transit vehicles (and carpools, if allowed) are assigned to the bus lane.

Simplifications from the HCM

The HCM method for estimating transit level of service for urban streets is documented in HCM Chapters 16 (Urban Street Facilities), 18 (Urban Street Segments), and 19 (Signalized Intersections). The transit LOS method presented above makes the following simplifications to the HCM method to improve its utility for planning applications:

- Bus running speeds are based solely on bus acceleration and deceleration characteristics rather than on motor vehicle running speeds (which are discounted in the HCM for midblock interference along the street segment).
- Bus stop delay is not adjusted for the location of the bus stop (e.g., near-side or far-side).
- Bus stop re-entry delay is not computed.
- Default values are provided for the a_1 passenger load travel time perception factor in lieu of the HCM equation that uses the exact passenger load as an input.
- A default value of 3 minutes excess wait time was used in lieu of computing it from on-time arrival statistics.

To take full advantage of these features the analyst must apply the HCM method as described in HCM Chapter 18, applying defaults as needed.

5. Signalized Intersections

Pedestrians

The HCM provides two pedestrian performance measures suitable for planning analyses of signalized intersections: average pedestrian delay and a pedestrian LOS score that reflects pedestrian comfort while crossing an intersection. Exhibit 112 lists the data required for these mea-

Exhibit 112. Required data for signalized intersection pedestrian analysis.

Input Data (units)	Used By DEL	Used By PLOS	Default Value
Traffic signal cycle length (s)*	•	•	60 (CBD), 120 (suburban)
Major street walk time (s)	•	•	See Section L or use 19 (CBD), 31 (suburban), 7 (minimum)
Minor street walk time (s)	•	•	See Section L or use 19 (CBD), 7 (suburban), 7 (minimum)
Number of lanes crossed on minor street crosswalk*		•	Must be provided
Number of channelizing islands crossed on minor street crosswalk		•	0
15-minute volume on major street (veh)*		•	Must be provided
Number of major street through lanes in the direction of travel*		•	Must be provided
Mid-block 85th percentile speed on major street (mph)		•	Posted speed limit
Right-turn on red flow rate over the minor street crosswalk (veh/h)		•	0 (right turns on red prohibited) Must be provided (otherwise)
Permitted left-turn volume over the minor street crosswalk (veh/h)		•	0 (protected left-turn phasing) 10% of through 15-minute volume (permitted left-turn phasing) 5% of through 15-minute volume (protected-permitted left-turn phasing)

Notes: See HCM Chapter 19 for definitions of the required input data.
DEL = delay, PLOS = pedestrian level of service, CBD = central business district.
*Input data used by or calculation output from the HCM urban street automobile LOS method.

sures and provides suggested default values. The HCM also provides calculation methods for assessing intersection corner circulation area and crosswalk circulation area, but these typically require more detailed data than would be available for a planning analysis.

Pedestrian Delay

Average pedestrian delay for a given signalized crosswalk is calculated as follows:

$$d_p = \frac{(C - g_{\text{Walk}})^2}{2C} \qquad \text{Equation 173}$$

where

d_p = average pedestrian delay (s),
C = cycle length (s), and
g_{Walk} = effective walk time for the crosswalk (s).

Pedestrian LOS Score

The HCM provides a method (Equations 19-71 through 19-76 in Chapter 19, Signalized Intersections) for calculating a pedestrian LOS score (and associated LOS letter using HCM Exhibit 19-9) for signalized intersections. This score can be used on its own or integrated into the urban street pedestrian LOS procedures. Most of the method's inputs are required by the auto LOS method for signalized intersections or can be defaulted. An exception is the right-turn-on-red flow rate over the crosswalk being analyzed. The LOS score is sensitive to this input and a wide range of values are possible. The HCM recommends developing local default values for this variable for use in planning analyses.

Bicycles

The HCM provides two bicycle performance measures for signalized intersections: average bicycle delay and a bicycle LOS score that reflects bicyclist comfort while crossing an intersection. Exhibit 113 lists the data required for these measures and provides suggested default values.

Exhibit 113. Required data for signalized intersection bicycle analysis.

Input Data (units)	Used By: DEL	Used By: BLOS	Default Value
Traffic signal cycle length (s)*	•		60 (CBD), 120 (suburban)
Effective green time for bicycles (s)	•		Effective green time for parallel through automobile traffic*
15-minute bicycle flow rate (bicycles/h)	•		Must be provided
15-minute automobile flow rate (veh/h)*		•	Must be provided
Cross street width (ft)		•	Must be provided
Bicycle lane width (ft)		•	5 (if provided)
Outside lane width (ft)*		•	12
Shoulder/parking lane width (ft)		•	1.5 (curb and gutter only) 8 (parking lane provided)
Percentage of intersection approach and departure with occupied on-street parking (decimal)		•	0.00 (no parking lane) 0.50 (parking lane provided)
Number of parallel through lanes (shared or exclusive)*		•	Must be provided

Notes: See HCM Chapter 19 for definitions of the required input data.
DEL = delay, BLOS = bicycle level of service, CBD = central business district.
*Input data used by or calculation output from the HCM urban street automobile LOS method.

Bicycle Delay

When bicyclists share the lane with automobile traffic, bicyclist delay is the same as automobile delay and can be calculated using Equation 97 (see Section L5). When bicyclists have their own lane, bicycle delay is calculated as follows:

$$d_b = \frac{0.5C(1-g_b/C)^2}{1-\min\left[\frac{v_{bic}}{c_b}, 1.0\right]\frac{g_b}{C}} \qquad \text{Equation 174}$$

$$c_b = s_b \frac{g_b}{C} \qquad \text{Equation 175}$$

where

d_b = average bicycle delay (s),
g_b = effective green time for the bicycle lane (s),
C = cycle length (s),
v_{bic} = bicycle flow rate (bicycles/h),
c_b = bicycle lane capacity (bicycles/h), and
s_b = bicycle lane saturation flow rate (bicycles/h) = 2,000.

Bicycle LOS Score

The HCM provides a method (Equations 19-79 through 19-82) for calculating a bicycle LOS score (and associated LOS letter using HCM Exhibit 19-9) for signalized intersections. This score can be used on its own or integrated into the urban street bicycle LOS procedures. Most of the method's inputs are required by the auto LOS method for signalized intersections or can be defaulted.

Transit

The HCM does not provide a transit LOS score for signalized intersections; the impacts of signalized intersections on bus speeds are incorporated into the segment and facility LOS scores (see Section O4).

6. STOP-controlled Intersections

Pedestrians

Two-Way Stops and Midblock Crossings

The HCM 2016 provides a method for estimating pedestrian delay crossing the major street at two-way STOP-controlled intersections and at midblock crosswalks. Exhibit 114 lists the required data.

Exhibit 114. Required data for two-way STOP-controlled intersection pedestrian delay calculation.

Input Data (units)	Default Value
Crosswalk length (ft)	Must be provided
Average pedestrian walking speed (ft/s)	3.5
Pedestrian start-up time and end clearance time (s)	3
Number of through lanes crossed	Must be provided
Vehicle flow rate during the peak 15 min (veh/s)	Must be provided; note the units of veh/s

Note: See HCM Chapter 20 for definitions of the required input data.

When a pedestrian refuge area is available in the street median, pedestrians can cross the street in two stages. In this case, delay should be calculated separately for each stage of the crossing and totaled to determine the overall delay.

First, pedestrian delay is calculated for the scenario in which motorists do not yield to pedestrians (i.e., pedestrians must wait for a suitable gap in traffic). This calculation neglects the additional delay that occurs when pedestrian crossing volumes are high enough that pedestrian platoons form (i.e., some pedestrians have to wait for the pedestrians ahead of them to step off the curb before they can enter the crosswalk). The following equations are used:

$$t_c = \frac{L}{S_p} + t_s \qquad \text{Equation 176}$$

$$P_b = 1 - e^{\frac{-t_c v}{N_L}} \qquad \text{Equation 177}$$

$$P_d = 1 - (1 - P_b)^{N_L} \qquad \text{Equation 178}$$

$$d_g = \frac{1}{v}(e^{vt_c} - vt_c - 1) \qquad \text{Equation 179}$$

$$d_{gd} = \frac{d_g}{P_d} \qquad \text{Equation 180}$$

where

t_c = critical headway for a single pedestrian (s),
S_p = average pedestrian walking speed (ft/s),
L = crosswalk length (ft),
t_s = pedestrian start-up time and end clearance time (s),
P_b = probability of a blocked lane (i.e., an approaching vehicle at the time the pedestrian arrives at the crosswalk that prevents an immediate crossing),
P_d = probability of a delayed crossing,
N_L = number of through lanes crossed,
v = vehicular flow rate (veh/s),
d_g = average pedestrian gap delay (s), and
d_{gd} = average gap delay for pedestrians who incur nonzero delay.

When motorists yield to pedestrians, pedestrian delay is reduced. The average pedestrian delay in this scenario is calculated as follows:

$$d_p = \sum_{i=1}^{n} h(i - 0.5)P(Y_i) + \left(P_d - \sum_{i=1}^{n} P(Y_i) \right) d_{gd} \qquad \text{Equation 181}$$

where

d_p = average pedestrian delay (s),
i = sequence of vehicle arrivals after the pedestrian arrives at the crosswalk,
n = average number of vehicle arrivals before an adequate gap is available = Int(d_{gd}/h),
h = average vehicle headway for each through lane (s),
P_d = probability of a delayed crossing,
$P(Y_i)$ = probability that motorist i yields to the pedestrian, from Exhibit 115, and
d_{gd} = average gap delay for pedestrians who incur nonzero delay.

The motorist yielding rate M_y is an input to the equations in Exhibit 115, and all other variables in the exhibit are as defined previously. Yielding rates for a selection of pedestrian crossing treatments are given in Exhibit 20-24 in HCM Chapter 20, Two-Way STOP-controlled Intersections. Alternatively, local values can be developed from field observations.

Exhibit 115. Equations for calculating probability of vehicles yielding to a crossing pedestrian.

Lanes Crossed	Probability of Vehicle *i* Yielding	
1	$P(Y_i) = P_d M_y (1 - M_y)^{i-1}$	Equation 182
2	$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{\left(2P_b[1 - P_b]M_y\right) + \left(P_b^2 M_y^2\right)}{P_d}\right]$	Equation 183
3	$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right]\left[\frac{P_b^3 M_y^3 + 3P_b^2(1 - P_b)M_y^2 + 3P_b(1 - P_b)^2 M_y}{P_d}\right]$	Equation 184
4	$P(Y_i) = \left[P_d - \sum_{j=0}^{i-1} P(Y_j)\right] \times \left[\frac{P_b^4 M_y^4 + 4P_b^3(1 - P_b)M_y^3 + 6P_b^2(1 - P_b)^2 M_y^2 + 4P_b(1 - P_b)^3 M_y}{P_d}\right]$	Equation 185

All-Way Stops

The HCM 2016 provides a qualitative discussion of contributors to pedestrian delay at all-way STOP-controlled intersections. However, the research base does not exist to provide a calculation method.

Bicycles

The HCM 2016 provides qualitative discussions of bicycle delay at two-way and all-way STOP-controlled intersections. However, the research base does not exist to provide calculation methods.

Transit

Buses will experience the same amount of control delay as other motor vehicles at these intersections.

7. Roundabouts

Pedestrian delay at roundabouts can be estimated using the methods for two-way STOP-controlled intersections (see Section O6). The HCM provides no quantitative method for estimating bicycle delay, although it can be expected to be similar to vehicular delay, if bicyclists circulate as vehicles, or to pedestrian delay, if bicyclists dismount and use the crosswalks. Buses will experience the same amount of control delay as other motor vehicles.

8. Off-Street Pathways

The HCM 2016 provides LOS measures for three combinations of modes and facility types:

- Pedestrians on an exclusive off-street pedestrian facility,
- Pedestrians on a shared-use path, and
- Bicyclists on an exclusive or shared off-street facility.

Exhibit 116 lists the required data for analyzing each of these situations.

Exhibit 116. Required data for off-street pathway analysis.

Input Data (units)	Used By PEX	Used By PSH	Used By BIKE	Default Value
Facility width (ft)	•		•	Must be provided
Effective facility width (ft)	•			Same as facility width
Pedestrian volume (ped/h)	•			Must be provided
Bicycle volume (bicycles/h)		•		Must be provided
Total path volume (p/h)			•	Must be provided
Bicycle mode split (%)			•	55% of path volume
Pedestrian mode split (%)			•	20% of path volume
Runner mode split (%)			•	10% of path volume
Inline skater mode split (%)			•	10% of path volume
Child bicyclist mode split (%)			•	5% of path volume
Peak hour factor (decimal)	•	•	•	0.85
Directional volume split (decimal)		•	•	0.50
Average pedestrian speed (ft/min)	•			300
Average pedestrian speed (mph)		•	•	3.4
Average bicycle speed (mph)		•	•	12.8
Average runner speed (mph)			•	6.5
Average inline skater speed (mph)			•	10.1
Average child bicyclist speed (mph)			•	7.9
SD of pedestrian speed (mph)			•	0.6
SD of bicycle speed (mph)			•	3.4
SD of runner speed (mph)			•	1.2
SD of inline skater speed (mph)			•	2.7
SD of child bicyclist speed (mph)			•	1.9
Segment length (mi)			•	Must be provided
Walkway grade ≤ 5% (yes/no)	•			Yes
Pedestrian flow type (random/platooned)	•			Random
Centerline stripe presence (yes/no)			•	No

Source: Default values from Hummer et al. (2006), except for effective facility width.

Notes: See HCM Chapter 24 for definitions of the required input data.

PEX = pedestrian LOS on an exclusive path, PSH = pedestrian LOS on a shared path, BIKE = bicycle LOS on all types of off-street pathways, SD = standard deviation.

Pedestrians on an Exclusive Off-Street Facility

Pedestrian LOS on an exclusive facility is based on the average space available to pedestrians. It is calculated using the following three equations:

$$v_{15} = \frac{v_h}{4 \times PHF} \quad \text{Equation 186}$$

$$v_p = \frac{v_{15}}{15 \times W_E} \quad \text{Equation 187}$$

$$A_p = \frac{S_p}{v_p} \quad \text{Equation 188}$$

where

v_{15} = pedestrian flow rate during peak 15 min (p/h),
v_h = pedestrian demand during analysis hour (p/h),
PHF = peak hour factor,
v_p = pedestrian flow per unit width (p/ft/min),
W_E = effective facility width (ft),

A_p = average pedestrian space (ft²/p), and
S_p = average pedestrian speed (ft/min).

Average pedestrian space is converted into an LOS letter using Exhibit 24-1 (for random pedestrian flow) or Exhibit 24-2 (when pedestrian platoons form) in HCM Chapter 24, Off-Street Pedestrian and Bicycle Facilities. HCM Exhibit 24-18 can be used to estimate the reduction in average pedestrian speed that occurs when walkway grades exceed 5%. The LOS result is highly sensitive to the average pedestrian speed provided as an input.

Pedestrians on a Shared Off-Street Facility

Pedestrian LOS on a shared off-street facility is based on the number of times per hour an average pedestrian meets or is passed by bicyclists using the path. The weighted number of meeting and passing events is calculated as follows:

$$F_p = \frac{Q_{sb}}{PHF}\left(1 - \frac{S_p}{S_b}\right) \quad \text{Equation 189}$$

$$F_m = \frac{Q_{ob}}{PHF}\left(1 + \frac{S_p}{S_b}\right) \quad \text{Equation 190}$$

$$F = \left(F_p + 0.5F_m\right) \quad \text{Equation 191}$$

where

F_p = number of passing events (events/h),
F_m = number of meeting events (events/h),
Q_{sb} = bicycle demand in same direction (bicycles/h),
Q_{ob} = bicycle demand in opposing direction (bicycles/h),
PHF = peak hour factor,
S_p = mean pedestrian speed on path (mph),
S_b = mean bicycle speed on path (mph), and
F = weighted total events on path (events/h).

The weighted total events F is converted into an LOS letter using HCM Exhibit 24-4. The LOS result is sensitive to the peak hour factor provided as an input.

Bicyclists on an Off-Street Facility

Bicycle LOS on all types of off-street facilities is based on a bicycle LOS score that considers:

- The average number of times per minute a bicyclist meets or is overtaken by other path users,
- The path width,
- The presence or absence of a centerline stripe, and
- The average number of times per minute a bicyclist is delayed in passing another path user (for example, because an oncoming path user is in the way).

At a minimum, total path width and the total number of hourly path users must be provided, although results will be more accurate if the actual mode split of path users (bicyclists, pedestrians, runners, inline skaters, and child bicyclists) is known or can be defaulted using local values. The bicycle LOS score is particularly sensitive to the bicycle mode split, the peak hour factor, and the directional distribution provided as inputs, and somewhat sensitive to whether or not a centerline stripe is present. HCM Exhibit 24-5 is used to convert the bicycle LOS score into an LOS letter.

The calculation process requires a large number of computations, and the use of a computational engine is recommended. The FHWA project (Hummer et al. 2006) that developed the method developed an engine, which can be downloaded from http://www.fhwa.dot.gov/publications/research/safety/pedbike/05138/SharedUsePathsTLOSCalculator.xls. The FHWA computational engine applies the peak hour factor in a different order in the computational sequence than the HCM implementation of the method does. However, any difference between the two methods is negligible for planning purposes.

9. References

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