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Multimodal Level of Service Analysis for Urban Streets: Users Guide

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The enclosed Users Guide is a draft being circulated to local agencies for testing and evaluation. We would appreciate hearing about your experiences using the multimodal LOS method and any advice you might have on how to improve its utility for local and state agencies operating urban streets. We would also appreciate any suggestions you might have on how this users guide might be improved. Please send your comments to nchrp370@dowlinginc.com.

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I. INTRODUCTION

An urban street is unique among the various facility types operated by public agencies, because its right-of-way is shared by multiple modes of travel, each using their assigned portion of the right-of way. To adequately evaluate the quality of service provided by the facility, one must consider the implications of facility design and operation on the auto driver, the bus passenger, the bicyclist and the pedestrian.

This users guide presents the multimodal level of service (MMLOS) analysis method for urban streets. It consists of a set of recommended procedures for predicting traveler perceptions of quality of service and performance measures for urban streets. These procedures consider the needs of people using the four major modes of travel on the street, their impacts on each other as they share the street, and their mode specific requirements for street design and operation.

ORGANIZATION

This users guide is organized as follows:

1. Introduction – Provides overview of scope and limits of methodologies. Alternative modeling approaches (Tools) are identified. The basic terminology is described.
2. Methodology – Describes the methodologies for estimating level of service and performance measures.
3. Application – Provides a step-by-step procedure for applying the methodologies.
4. Accuracy and Sensitivities – Provides information on the sensitivity of the estimated multimodal level of service and facility performance to key input variables. Provides information on the confidence intervals for the predicted level of service and performance.
5. Facility Sizing/Design Aids – Provides service volume and other look-up tables for quickly estimating the basic facility design parameters (number of lanes, right of way, medians, multimodal features, signal spacing, etc.) required to achieve a target multimodal level of service or performance standard for forecasted modal demand levels.
6. Example Problems – Worked example problems illustrating the application of the methodologies.

SCOPE AND LIMITATIONS

This users guide presents the recommended procedures for predicting traveler perceptions of quality of service and performance measures for urban streets.

An urban street is defined as a public road with traffic signal control at least once every 2 miles. The multimodal level of service (MMLOS) method is generally not designed to be applied to residential streets, nor to rural roads with infrequent or no signal control. Users should not be afraid to over-rule the computed results with common sense when applying the level of service method in these situations.

The MMLOS method is not well suited to consider the needs of and the characteristics of motorized or other vehicles incapable of exceeding 25 mph for sustained periods of time (with the exception of bicycles, which this users guide specifically addresses). Motorized or hand-propelled wheel chairs, rickshaws, horse-drawn carriages, motorized bicycles, some scooters, and some golf carts are examples of vehicles that the method cannot address well.

The MMLOS method is designed for analysis of steady state conditions during a specified analysis period. They neither address the dynamic development and dissipation of congestion during the peak period, nor can they identify the starting and ending times of congestion. The analyst should consider alternative analysis approaches, such as simulation modeling, if a dynamic analysis is required.

The MMLOS method addresses the perceived quality of service for passenger car (automobile) drivers, bus passengers, bicycle riders, and pedestrians to the extent that these perceptions are influenced by factors that fall exclusively within the right of way of the urban street. Environmental factors that fall outside of the right-of way, such as buildings, parking lots, scenery, and landscaped front yards are specifically excluded from the LOS methodology, because these factors are not specifically under the direct control of the agency operating the urban street.

The MMLOS does not address perceived quality of service for commercial vehicle drivers (trucks, taxis, etc.), auto passengers, messenger and delivery services, recreational users, and rail transit riders.

Transit level of service is designed to apply only to scheduled, fixed route public transit service operating within the street itself. Only service with pickup/drop-off service within the section of the street being studied is included in the LOS computations. Through transit service, underground service, taxi cab service, jitney (semi-private) service, and demand responsive service are not covered by the MMLOS method.

The MMLOS methodology is not designed to be applied to wheel chair travel, golf carts, motorized bikes, rickshaws, horse drawn vehicles, scooters, and motorcycles. However, the analyst may, with care, potentially adapt some of the LOS methods to these specialized vehicle types.

The MMLOS methodology is not designed to be applied to streets with railroad crossings, where rail traffic is so frequent that its impacts on performance and level of service cannot be neglected.

Further limitations on the specific methods for estimating level of service and approaches for overcoming these limitations are provided later in the methodology section, under "Treatment of Special Cases" following the description of each mode's LOS method.

ANALYSIS TOOL ALTERNATIVES

The performance and level of service analysis methods presented here are designed for a steady state analysis, therefore the analysis of dynamic conditions (such as the determination of the beginning and end times of congestion) will require the use of an alternative analysis tool.

QUALITY OF SERVICE AND GOOD PLANNING/DESIGN PRACTICE

Quality of service (as expressed in terms of letter grade levels of service) is an indicator of the traveling public's perceived degree of satisfaction with the traveling experience provided by the urban street under prevailing demand and operation conditions.

Quality of service is a "selfish" measure. It considers only the perspective of the traveler or the prospective traveler. It does not take into account how many people will actually use the facility or how expensive it is to the agency and the general public to provide the facility. It does not consider environmental concerns or collision rates.

Quality of service is therefore only one of several factors that must be taken into account in good design and planning practice. It is NOT the "be all and end all" of design or planning. Planning and design must take into account additional factors like capacity utilization, accessibility, safety, cost-effectiveness, the effect on the environment, and each agency's goals and objectives.

Level of service results must be evaluated in the context of other planning and design considerations. Level of service "F", by itself, does NOT mean that there is a problem that the agency must fix. Similarly, level of service "A", by itself, does NOT mean that there are no problems.

TERMINOLOGY

This users guide employs the following terminology:

An **Urban Street** is defined as a public road with traffic signal control at least once every 2 miles. The road can be located in a rural or an urban area as long as the signal control meets the required minimum spacing.

The **Study Length** of a street is the portion of the entire street that is selected for evaluation. The study length can be much shorter or much longer than 2 miles, as determined by the purpose of the analysis.

The study length is divided into analysis **segments**. Each segment consists of a length of street between intersections plus the downstream intersection at the end of the segment. The study length is divided into segments. Each segment is selected so as to ensure that the demand, control, and geometry are relatively uniform within each segment. The variation in demand, control, or geometry ideally should be greater between segments than within segments.

Demand includes vehicular traffic, transit ridership, bicyclists, and pedestrians. **Control** includes posted speed limits, traffic signals, stop signs, traffic calming devices, and other devices intended to influence vehicle speeds. **Geometry** includes number of lanes, shoulders, parking lanes, sidewalks, bicycle lanes, planter strips, medians, and etcetera.

An **intersection** is any point on the street where through traffic is subject to signal control, stop-sign control, or yield-sign control. A signalized pedestrian cross-walk would be considered an intersection for the purposes of the MMLOS method. A signalized driveway on an urban street would be considered an intersection. A roundabout on an urban street would be considered an unsignalized intersection on that street.

In addition, an intersection also occurs at any point on the urban street where another public street meets the subject street. Thus a two-way stop intersection with a public street is considered an intersection, even though through traffic on the subject street does not stop or yield.

A **mode** is a method of travel. While many more modes exist in real life, MMLOS method focuses on only four modes of person-travel: auto driver, bus passenger, bicycle rider, and pedestrian.

Auto is generally used in its generic sense in this users guide. The term, as used here, includes all motor vehicles on the street, with the exception of transit vehicles. However, the auto level of service computed by the MMLOS method applies to private vehicle drivers only.

The **Transit** service that can be evaluated according to the MMLOS method is limited to only scheduled public transit vehicles operating within the street and picking up/dropping off passengers within the study section of the street. The vehicle may run on rubber tires or steel wheels (e.g. light rail or trolley), as long as it operates on the street. Express, inter-city, and private vehicles that do not serve passengers within the study section of street are not included in the transit LOS estimated by the MMLOS method.

Bicycle includes any human powered vehicle legally allowed to operate on the public street in the same lanes as automobiles.

Pedestrians include any person of school age or older walking on-foot.

Quality of Service is a measure of the traveling public's perceived of degree of satisfaction with their traveling experience on the facility. Quality of service includes the perceptions of non-users of the facility as well, who are potential users, but have chosen not to use the facility because they perceive it to provide inadequate quality of service.

Speed is defined as the unit distance per unit time rate of travel. **Average Speed** is the sum of the vehicle-miles traveled (VMT) over a set distance divided by the vehicle-hours traveled (VHT) expended by the vehicles to cover the distance. For pedestrians average speed is the person-miles traveled (PMT) divided by the person-hours traveled (PHT).

The number of **Stops** per vehicle is defined as the average number of times that a vehicle speed drops to zero miles per hour (mph) from a speed greater than zero mph. Because many measuring devices do not have the precision to identify exactly zero miles per hour, a tolerance must be provided for field measurements of stops. For field measurements, a stop is considered to occur any time a measured speed drops from above 5 mph to a speed below 5 mph.

Free-Flow Speed is the theoretical speed of traffic at very low flow rates for the given street geometry and in the absence of all traffic control devices (such as traffic signals and roundabouts) except speed limit signs.

Mode and methodology specific terms are addressed as they come up in the description of each LOS and performance estimation method.

II. METHODOLOGY

This section provides a general overview of the methodologies for estimating multimodal level of service and for estimating additional modal performance measures such as travel time, speed, delay, stops, and queuing for an urban street.

MULTIMODAL LEVEL OF SERVICE ANALYSIS FRAMEWORK

Level of service (LOS) is used to translate complex numerical performance results into a simple letter grade system representative of the travelers' perception of the resulting quality of service provided by the facility. The letter grade level of service hides much of the complexity of facility performance in order to simplify decision-making regarding whether or not facility performance is generally acceptable and whether or not a change in this performance is likely to be perceived as significant by the general public.

Level of service is a quantitative stratification of quality of service into six letter grades with letter grade "A" representing the "best" quality of service, and letter grade "F" representing the "worst" quality of service. "Best" and "Worst" are left undefined, allowing the traveling public to self-identify the "best" and "worst" conditions based on their own experience and perceptions for each individual situation.

Level of service is a quantitative stratification of quality of service into 6 levels of service.

Research indicates that the traveling public perceives less than six levels of service, however the six letter-grade (A-F) system has been retained to provide agencies with additional thresholds of performance with which to analyze performance.

In addition, while there is a wide range in the levels of service reported by the traveling public for any given condition, this LOS methodology reports only a single, weighted average letter grade for the given condition. This is designed to simplify the task of agency decision-making. Instead of reporting a probability distribution of LOS grades for a facility, the LOS methodology reports a single representative letter grade LOS for the facility.

The methodology provides for the estimation of a separate mean level of service for each of four modes of travel on the urban street: auto driver, bus passenger, bicyclist, and pedestrian. Other modes of travel; commercial vehicle, truck driver, auto passenger, recreational travel, and messenger/delivery service are not covered by this methodology.

The methodology does not provide for the computation of an overall weighted average of the LOS results across the four modes of travel. It enables the analyst to see the changes in LOS from one mode to the other as changes are made to the design and operation of the urban street. Weighing the trade-offs of improving the LOS for one mode versus worsening it for another mode are left to the analyst and the public agency operating the urban street.

The Highway Capacity Manual (2000) has historically relied upon a single performance measure to predict level of service. Research indicates however that the traveling public takes into account several factors in evaluating the quality of service provided by an urban street. Consequently, this users guide presents models of level of service that combine these factors into a predicted level of service. The four modal LOS models presented below output numerical ratings, which must be converted into the traditional A-F letter grade system. Exhibit 1: LOS Letter Grade Numerical Equivalents, is used to convert the numerical outputs into letter grades.

Exhibit 1: LOS Letter Grade Numerical Equivalents

LOS Model Outputs	LOS Letter Grade
Model <=2.00	A
2.00 < Model <= 2.75	B
2.75 < Model <= 3.50	C
3.50 < Model <= 4.25	D
4.25 < Model <= 5.00	E
Model > 5.00	F

Notes:
1) If any directional segment hourly volume/capacity ratio (v/c) exceeds 1.00 for any mode, that direction of street is considered to be operating at LOS F for that mode of travel for its entire length (regardless of the computed level of service).
2) If the movement of any mode is legally prohibited for a given direction of travel on the street, then the level of service for that mode is LOS "F" for that direction.

Division of Street Into Analysis Segments

The portion of the street to be evaluated is defined as the study section of the street. Each direction of travel on the street is evaluated separately.

The LOS estimation methods require that the demand, control, and geometry of the study section of the street be relatively uniform within the analysis segment. Since demand, control and geometric conditions are rarely uniform over the length of a street, it is usually necessary to divide the study section of the street into segments. Each segment consists of a piece of the street (usually between two intersections) where the demand, control, and geometric conditions are uniform.

Demand includes vehicular traffic, transit ridership, and pedestrian flow rates. Segments should be selected so as to ensure that all three of these modal demands are relatively constant within a segment. Bicycle flows do not currently enter into the LOS computations and can be allowed to vary within a segment if only an LOS analysis is to be performed. However, if bicycle performance measures are to be computed and bicycle flow rates are high enough to influence bicycle operations, then the segments should be selected so that bicycle flows are also relatively constant within the segment.

Control includes posted speed limits, traffic signals, stop signs, traffic calming devices, and other devices intended to influence vehicle speeds. Segments should be selected so that control devices that slow or stop traffic (such as signals, all-way stops, and roundabouts) are located at the end points of an analysis segment.

Geometry includes number of lanes, shoulders, parking lanes, sidewalks, bicycle lanes, planter strips, medians, etcetera. The road cross-section (lane widths, etc.) should be relatively constant within the segment.

Auto Level Of Service

Auto level of service is a function of the average travel speed over the length of the street and the average number of stops per mile. The auto level of service rating for an urban street is the weighted average of the sum of the probabilities of people reporting each LOS rating multiplied by a system of weights that gives greater weight to the proportion of people who perceive poorer level of service.

> Auto level of service is a function of stops and left turn lanes. The more stops per mile, the poorer the level of service. The more intersections with exclusive left turn lanes, the better the level of service.

street. All signalized or unsignalized intersections of public roads are counted. Private driveway intersections are not counted, unless they are signal controlled.

Special Cases

Treatment of Non-Uniform Street Segments

The demand, geometry, and control present on any given segment should ideally be relatively uniform within the segment, however; some variation is tolerable (less than 10% of the mean).

Left turn bays, right turn bays, short lane additions or drops, and other geometric changes in the vicinity of the downstream intersection of the segment do not trigger the need to divide the segments into subsegments because these geometric aspects are included in the estimation of intersection v/c ratio and stops.

If there is a sudden demand increase or decrease in the middle of the segment, such as might occur at a large parking garage, then the segment should be divided into two (or more) subsegments, each with its own appropriate demand level.

Generally, a reduction in through lanes in the middle of a segment, such as might occur at a bridge, would trigger the need to subdivide the segment into subsegments.

If in doubt as to the seriousness of the geometric or demand variation within the segment, the segment should be divided into additional subsegments and the LOS evaluated to see if the change significantly impacts the computed LOS and facility performance.

Treatment of One-Way Street Facilities

If one direction of auto travel is prohibited, e.g. a one-way street, then the computations for the allowed direction of travel should proceed normally. For the prohibited direction of travel the LOS is set at “F”.

Treatment of Facilities with Unsignalized Intersections

For an existing conditions analysis, the number of stops per mile can be measured in the field over the study length of the facility and used to compute the LOS.

If forecasting future LOS, the Highway Capacity Manual (2000) does not currently provide a method for estimating stops per vehicle. Until such a methodology becomes available, the analyst can estimate the number of stops per vehicle for each street segment approaching a stop sign at 1.00 stops per vehicle. For forecasted v/c ratios greater than 1.00, set the auto LOS at “F”.

The number of stops per vehicle for stop signs is added to the estimated number of stops per vehicle for each of the traffic signals and divided by the study length to obtain the average number of stops per mile for the study length of street.

For street segments approaching all other unsignalized intersections (where the approaching traffic is not required to stop), the number of stops per vehicle should be set to zero as long as the intersection approach volume/capacity ratio is below 1.00. For volume/capacity ratio values equal to or greater than 1.00, the segment of street approaching the intersection should be set at LOS “F”.

Treatment of Bus Lanes and Bus Streets

In the case of bus streets, the auto LOS is, by definition, LOS “F” (since autos cannot access this street). The transit and pedestrian LOS are computed normally, with transit vehicles being the only motorized vehicles on the street. If bicycles are allowed in the bus street then bicycle LOS is computed normally, otherwise, it is set to LOS “F” for bicycles.

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 or taxis, if allowed) are assigned to the bus lane.

Treatment of Railroad Crossings

The LOS methodology is not designed to account for the impacts of railroad crossings with frequent train traffic. If train frequencies are less than 1 per hour, their impacts of perceived auto level of service can be neglected.

Transit Level of Service

Transit level of service is a function of its accessibility by pedestrians, the amenities at the bus stop, the waiting time for the bus, and the mean speed of the bus.

Better pedestrian access, better shelters, more frequent bus service and higher speed bus service all improve the perceived level of service for bus transit.

The transit level of service (LOS) is based on a combination of the access experience, the waiting experience, and the ride experience. The access experience is represented by the pedestrian level of service score for pedestrian access to bus stops in the direction of travel along the street. The waiting and riding experiences are combined into a transit wait/ride score. The formula below is used to combine the various experiences into a single LOS score.

Transit LOS Score = 6.0 – 1.50 * *TransitWaitRideScore + 0.15 * PedLOS* Equation 4

where:

PedLOS	=The pedestrian LOS numerical value for the direction of the facility being analyzed (A=1, F=6).
TransitWaitRideScore	=The transit ride and waiting time score, a function of the average headway between buses and the perceived travel time rate via bus.

The computed transit level of service score is converted to a letter level of service grade using the equivalencies given in above Exhibit 1

Estimation of the Pedestrian LOS

The pedestrian LOS for the urban street is estimated using the pedestrian LOS model described in a later section of this users guide.

Estimation of the Transit Wait/Ride Score

The transit wait/ride score is a function of the headway between buses and the perceived travel time rate via bus for the urban street.

$$\textbf{TransitWaitRideScore} = f_h * f_{ptt} \qquad \textbf{Equation 5}$$

Where:

f_h	= headway factor = the multiplicative change in ridership expected on a route at a headway *h,* relative to the ridership at 60-minute headways;
f_{ptt}	= perceived travel time factor = the multiplicative change in ridership expected at a perceived travel time rate *PTTR,* relative to the ridership expected at a baseline travel time rate. The baseline travel time rate is 4 minutes/mile except for central business districts of metropolitan areas with over 5 million population, in which case it is 6 min/mile.

Headway Factor

The headway factor (f_h) is the ratio of the estimated patronage at the prevailing average bus headway to the estimated patronage at a base headway of 60 minutes. The patronage values for the two headways (the actual or predicted headway and the base headway of 60 minutes) are computed based upon an assumed set of patronage elasticities which relate the percentage change in ridership to the percentage change in headways.

Note that only the buses and bus routes that actually stop to pickup or drop off passengers within the study section of the street should be included in the computation of mean bus headways for the street. Express bus service without at least one bus stop on the street would be excluded.

Exhibit 3: Headway Factor (f_h) Look-Up Table can be used to obtain Fh for a range of bus headways. It was computed using a set of assumed passenger elasticities taken from TCRP (Transit Cooperative Research Program) research.

Exhibit 3: Headway Factor (f_h) Look-Up Table

Headway (minutes)	Frequency (Bus/hr)	f(h)
60	1.00	1.00
45	1.33	1.33
30	2.00	2.00
15	4.00	2.80
10	6.00	3.16
5	12.00	3.79

This table was constructed using elasticities given in Exhibit 4. If the analyst has information indicating that a different set of patronage elasticities are appropriate, then this table for f_h should be reconstructed based on the recomputed patronage ratios for the actual or predicted headway and the base headway.

Exhibit 4: Elasticities Used to Construct Headway Factor (Fh) Lookup Table

Bus Headways	Assumed Patronage Elasticity
30-60 minutes	+1.0
15-30 minutes	+0.5
10-15 minutes	+0.3
< 10 minutes	+0.2

Source: Derived from data reported in TCRP Report 95, Chapter 9

The f_h values in Exhibit 3 can be approximated using the following formula:

$$f_h = 4 * \exp(-0.0239 * Headway)$$ **Equation 6**

Where:

f_h	= headway factor
Headway	= Average number of minutes between buses

Perceived Travel Time Factor

The perceived travel time factor is estimated based on the perceived travel time rate and the expected demand elasticity for a change in the perceived travel time rate.

$$F_{PTTR} = \frac{[(e-1)BTTR - (e+1)TTR]}{[(e-1)TTR - (e+1)BTTR]}$$ **Equation 7**

Where:

F(PTTR) = Perceived Travel Time Factor

PTTR = Perceived Travel Time Rate (min/mi)
BTTR = Base Travel Time Rate (min/mi) Use 6 minutes per mile for the main central business district of metropolitan areas with population greater than or equal to 5 million. Use 4 minutes per mile for all other areas.
e = ridership elasticity with respect to changes in the travel time rate. The suggested default value is –0.40, but local values may be substituted.

Exhibit 5 below illustrates the application of this equation for selected perceived travel time rates and a selected elasticity.

Exhibit 5: Example Perceived Travel Time Factors (F(PTTR))

	F(PTTR)	
BTTR:	4 min/mi	6 min/mi
PTTR (min/mi)		
2	1.31	1.50
2.4	1.22	1.41
3	1.12	1.31
4	1.00	1.17
6	0.85	1.00
12	0.67	0.76
30	0.53	0.58

Notes:

- F(PTTR) = Perceived Travel Time Factor
- PTTR = Perceived Travel Time Rate.
- BTTR = Base Travel Time Rate (default is 4 minutes per mile. 6 minutes per mile BTTR is used for the central business districts (CBD) of metropolitan areas with 5 million or greater population).
- Based on default value of –0.40 for elasticity.

The perceived travel time rate (PTTR) is estimated based on the mean speed of the bus service, the average excess wait time for the bus (due to late arrivals), the average trip length, the average load factor for the bus service, and the amenities at the bus stops.

$$PTTR = a_1 * IVTTR + a_2 * EWTR - ATR \qquad \textbf{Equation 8}$$

Where:

PTTR = Perceived travel time rate.

IVTTR = Actual in-vehicle travel time rate, in minutes per mile; (Default = 4.00)

EWTR = Excess wait time rate due to late arrivals (minutes/mile)

= Excess wait time/ average trip length (Default = 2.00).

a_1 = Passenger load weighting factor (a function of the average load on buses in the analysis segment during the peak 15 minutes) (Default = 1.00);

a_2 = 2 (wait time factor converting actual wait times into perceived wait times)

ATR = Amenity time rate = perceived travel time rate reduction due to the provision of certain bus stop amenities

In-Vehicle Travel Time Rate

The in-vehicle travel time rate is equal to the inverse of the mean bus speed converted to minutes per mile.

$$IVTTR = \frac{60}{Speed}$$ **Equation 9**

Where:
IVTTR = In-Vehicle Travel Time Rate (min/mi)r
Speed = Average speed of bus over study section of street (mph)

When field measurement of mean bus speed is not feasible, the mean schedule speed can be used. Identify two schedule points on the published schedule for the bus route(s). Measure the distance covered by the bus route(s) between the two points. Divide the measured distance by the scheduled travel time between the two schedule points. The bus speed estimation procedure given in the Highway Capacity Manual (2000) may be used to estimate future bus speeds.

The in-vehicle travel time rate is multiplied by a passenger load weighting factor (a1) to account for the increased discomfort when buses are crowded. Values of the passenger load weighting factor (a_1) are given in Exhibit 6 below.

Exhibit 6: Passenger Load Weighting Factor (a_1)

Load Factor (pass/seat)	a_1
≤0.80	1.00 default
1.00	1.19
1.10	1.41
1.20	1.62
1.30	1.81
1.40	1.99
1.50	2.16
1.60	2.32

Notes:
1) Load factor is the average ratio of passengers to seats for buses at the peak load point within the study section of the street. If bus load factor is not known, a default value of 1.00 can be assumed for the load weighting factor (a_1).

Exhibit 6 can be approximated with the following equation:

$$a_1 = Max\left\{1.00, 1.22 * LF + 0.33\left[(LF - 1) + \sqrt{(LF - 1)^2}\right]\right\}$$ **Equation 10**

Where:
a_1 = Passenger load weighting factor
LF = Load factor (passengers/seat) **

**Peak bus load factors are best measured in the field for the street sections being evaluated. However, peak load factors for the entire bus route (typically collected and reported by the bus operating agency) can be used to approximate the values for the subject street segments.

Excess Wait Time Rate

The excess wait time is the sum of the differences between the scheduled and actual arrival times for buses within the study section of the street divided by the number of observations. Early arrival without a corresponding early departure is counted as being on-time. However, early arrival with an early departure is counted as being "one headway" late for the purposes of computing the average excess wait time for the street.

In-Vehicle Travel Time Rate

The in-vehicle travel time rate is equal to the inverse of the mean bus speed converted to minutes per mile.

$$IVTTR = \frac{60}{Speed}$$ **Equation 9**

Where:

IVTTR = In-Vehicle Travel Time Rate (min/mi)r
Speed = Average speed of bus over study section of street (mph)

When field measurement of mean bus speed is not feasible, the mean schedule speed can be used. Identify two schedule points on the published schedule for the bus route(s). Measure the distance covered by the bus route(s) between the two points. Divide the measured distance by the scheduled travel time between the two schedule points. The bus speed estimation procedure given in the Highway Capacity Manual (2000) may be used to estimate future bus speeds.

The in-vehicle travel time rate is multiplied by a passenger load weighting factor (a1) to account for the increased discomfort when buses are crowded. Values of the passenger load weighting factor (a_1) are given in Exhibit 6 below.

Exhibit 6: Passenger Load Weighting Factor (a_1)

Load Factor (pass/seat)	a_1
≤0.80	1.00 default
1.00	1.19
1.10	1.41
1.20	1.62
1.30	1.81
1.40	1.99
1.50	2.16
1.60	2.32

Notes:

1) Load factor is the average ratio of passengers to seats for buses at the peak load point within the study section of the street. If bus load factor is not known, a default value of 1.00 can be assumed for the load weighting factor (a_1).

Exhibit 6 can be approximated with the following equation:

$$a_1 = Max\left\{1.00, 1.22 * LF + 0.33\left[(LF-1) + \sqrt{(LF-1)^2}\right]\right\}$$ **Equation 10**

Where:

a_1 = Passenger load weighting factor
LF = Load factor (passengers/seat) **

**Peak bus load factors are best measured in the field for the street sections being evaluated. However, peak load factors for the entire bus route (typically collected and reported by the bus operating agency) can be used to approximate the values for the subject street segments.

Excess Wait Time Rate

The excess wait time is the sum of the differences between the scheduled and actual arrival times for buses within the study section of the street divided by the number of observations. Early arrival without a corresponding early departure is counted as being on-time. However, early arrival with an early departure is counted as being "one headway" late for the purposes of computing the average excess wait time for the street.

The excess wait time rate is the excess wait time (in minutes) divided by the mean passenger trip length for the bus route(s) within the study section of the street.

For average passenger trip length a default value can be taken from national average data reported by the American Public Transit Association (APTA) (http://www.apta.com/research/stats/ridership/trlength.cfm). In 2004, the mean trip length for bus passenger-trips nationwide was 3.7 miles.

More locally specific values of average trip length can be obtained from the National Transit Database (NTD). Look up the annual passenger miles and annual unlinked trips in the transit agency profiles contained stored under NTD Annual Data Publications at: http://www.ntdprogram.gov/ntdprogram/pubs.htm#profiles. The mean trip length is the annual passenger-miles divided by the annual unlinked trips.

If field measurements of excess wait time are not feasible, excess wait time rate can be estimated based on a transit agency's reported "on-time rating" for the route(s), using the following equation.

Note that the analyst must use the same definition of "Late" as was used by the transit operator in defining on-time performance. Consult with Transit Capacity and Quality of Service Manual for additional information on estimating on-time performance.

$$EWTR = \frac{[Late * (1 - OTP)]^2}{ATL}$$ **Equation 11**

Where:
EWTR = Excess Wait Time Rate (min/mi)
Late = Minutes late before the agency counts a bus arrival as late.
OTP = On-Time Performance. Agency reported proportion of buses arriving on-time.
ATL =Average passenger trip length (miles)

Amenity Time Rate

The amenity time rate is the time value of various bus stop improvements divided by the mean passenger trip length. The mean passenger trip length is the same distance used to compute the Excess Wait Time Rate (described above).

$$ATR = \frac{1.3 * Shelter + 0.2 * Bench}{ATL}$$ **Equation 12**

Where:
ATR = Amenity Time Rate (min/mi)
Shelter = Proportion of bus stops in study section direction with shelters
Bench = Proportion of bus stops in study section direction with benches
ATL = Average passenger trip length (miles)

Notes:
1) Shelters with benches are counted twice, once as shelters, the second time as benches.

Computation of Facility LOS From Segment LOS

The level of service is computed separately for each direction of travel on each analysis segment.

The segment levels of service (for a given direction of travel) are combined into an overall directional level of service for the study section of street by taking a length weighted average of the segment levels of service for the analysis direction.

$$LOS(facility) = \frac{\sum LOS(i) * L(i)}{\sum L(i)}$$ **Equation 13**

Where:
LOS (facility) = LOS for subject direction of facility
LOS (segment) = LOS is subject direction for each segment (i)
L (segment) = Length of each segment (i)

Special Cases

Treatment of 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 Full Length of Study Section
If a passenger must transfer one or more times to continue on the same street, then the transfer waiting time should be added into the total travel time used to compute the mean speed of the bus service on the street. If some routes travel the length of the street while others do not, the analyst may compute a weighted average travel time across all of the bus routes including transfer waiting times. The weighted average travel time is divided into the analysis street length to obtain the weighted average mean speed for bus service on the street.

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

For cases where transit service is provided as a one-way loop, the analyst can compute the excess time and distance to go around the loop to reach the upstream destination and enter the information into the perceived travel time rate computation for the direction of travel without direct service.

Treatment of 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.

Treatment of Railroad Crossings
The LOS methodology is not designed to directly account for the impacts of railroad crossings on transit LOS. Since transit vehicles usually must stop at all railroad crossings, the crossings will reduce the speed of bus service.

If the analyst can estimate the added delay due to stops for railroad crossings and stops for trains, then this information can be used to estimate the effect on bus speeds on the street. The speeds can be used to estimate the transit LOS for the street with railroad crossings. Infrequent delays due to railroad crossings can be incorporated via the reliability (on-time performance) component of transit LOS

Bicycle Level of Service

The bicycle level of service is a weighted combination of the bicyclists' experiences at intersections and on street segments in between the intersections.

Bicycle LOS = 0.160*(ABSeg) + 0.011*(exp(ABInt)) + 0.035*(Cflt) + 2.85 Equation 14

Where

ABSeg = The length weighted average segment bicycle score
Exp = The exponential function, where e is the base of natural logarithms.
ABInt = Average intersection bicycle score
Cflt = number of unsignalized conflicts per mile, i.e., the sum of the number of unsignalized intersections per mile and the number of driveways per mile**

The output of this model is a numerical value, which must be translated to a level of service (LOS) letter grade. Exhibit 1 above provides the numerical ranges that coincide with each LOS letter grade.

Bicycle Segment LOS

The segment bicycle LOS is calculated according to the following equation:

BSeg = 0.507 Ln (V/(4*PHF*L)) + 0.199Fs*(1+10.38HV)^2 +7.066(1/PC)^2-0.005(We)^2+ 0.760 Equation 15

Where:

BSeg	= Bicycle score for directional segment of street.
Ln	= Natural log
PHF	= Peak Hour Factor (if unknown, use 0.90 as default value)
L	= Total number of directional through lanes
V	= Directional motorized vehicle volume (vph). (Note: V > 4 *PHF * L)
Fs	= Effective speed factor = 1.1199 ln(S - 20) + 0.8103
S	= Average running speed of motorized vehicles (mph) (Note: S >= 21)
HV	= Proportion of heavy vehicles in motorized vehicle volume. Note: if the auto volume is < 200 vph, the %HV used in this equation must be <= 50% to avoid unrealistically poor LOS results for low volume and high percent HV conditions.
PC	= FHWA's five point pavement surface condition rating (5=Excellent, 1=Poor) (A default of 3 may be used for good to excellent pavement)
We	= Average effective width of outside through lane (ft) = Wv - (10ft x %OSP) (ft) ** If W1 < 4 = Wv + W1 - 2 (10 x %OSP) (ft) ** Otherwise
%OSP	= Percentage of segment with occupied on-street parking
W1	= width of paving between the outside lane stripe and the edge of pavement (ft)
Wv	= Effective width as a function of traffic volume (ft) = Wt (ft) ** If V > 160 vph or street is divided = Wt*(2-(0.005 x V)) (ft) ** Otherwise
Wt	= Width of outside through lane plus paved shoulder (including bike lane where present) (ft) Note: parking lane can be counted as shoulder only if 0% occupied.

**Lightly used driveways, such as residential driveways, should generally be excluded from the driveway and unsignalized intersection counts used to compute the number of conflicts per mile. Unsignalized merges (where side street traffic does not have to stop before entering the arterial), such as might occur at the foot of a freeway off-ramp, should be given much greater weight in the computation of conflicts per mile. The degree of weighting is at the discretion of the analyst.

Bicycle Segment LOS is a function of the perceived separation between motor vehicle traffic and the bicyclist, parked vehicle interference, and the quality of the pavement. Higher vehicle volumes, higher percent heavy vehicles, and higher vehicle speeds decrease the perceived separation. A striped bike lane increases the perceived separation.

Available research does not provide information on whether or not motorcycles and mopeds impact bicyclists as much as passenger cars. It is left to the analyst's discretion to determine the extent to which motorcycles, golf carts, and mopeds should be included in the vehicle volumes used to estimate Bicycle Segment LOS.

Bicycle Intersection LOS

The intersection bicycle LOS is calculated according to the following equation:

Bint = -0.2144Wt + 0.0153*CD* + 0.0066 (V/(4*PHFL*)) + 4.1324** **Equation 16**

$$Bint = -0.2144Wt + 0.0153CD + 0.0066\left(V/(4 \cdot PHF \cdot L)\right) + 4.1324$$

Where:

Bint = bicycle intersection score
Wt = total width of outside through lane and bike lane (if present) on study direction of street (ft).
CD = The curb-to-curb width of the cross-street at the intersection (ft).
V = Volume of directional traffic (vph)
L = Total number of through lanes on the subject approach to the intersection

Computation of Facility LOS From Segment LOS

The level of service is computed separately for each direction of travel on each analysis segment.

The segment levels of service (for a given direction of travel) are combined into an overall directional level of service for the study section of street by taking a length weighted average of the segment levels of service for the analysis direction.

$$LOS(facility) = \frac{\sum LOS(i) * L(i)}{\sum L(i)}$$ **Equation 17**

Where:
LOS (facility) = LOS for subject direction of facility
LOS (segment) = LOS is subject direction for each segment (i)
L (segment) = Length of each segment (i)

Special Cases

Treatment of Sections With Significant Grades

The bicycle level of service 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 up-grades and down-grades on bicycle level of service. 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 manual did not provide a basis for computing such an adjustment. It is left to the discretion of the analyst.

Treatment of Sections with Parallel Bike/Ped Path

Auto and transit LOS are computed as for a standard street segment. The bicycle LOS is computed for both bicycles using the street and for bicycles using the parallel path. If the analyst has information on the split of bicycles using the parallel path and the street, then the resulting path and street LOS's are combined into a single LOS for bicycles based on the percent using each.

BLOS = %Using Street *BLOS(Street) + %Using Path * BLOS(Path) Equation 18

Where:

BLOS (Street) = Bicycle LOS for bicycles riding in the traveled way of the street.
BLOS (Path) = Bicycle LOS for bicycles using the parallel path.

The bicycle path LOS is computed using the path procedures provided in Chapter 18, Bicycles of the Highway Capacity Manual (2000).

Treatment of Bus Lanes, Bus Streets, and HIgh Bus Volumes

The bicycle LOS methodology is not designed to adequately represent bicyclist perceptions of level of service when they are operating on streets with frequent bus service with frequent stops requiring bicyclists to frequently swerve 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 level of service. The weighting factor would be at the analyst's discretion.

Treatment of Railroad Crossings

The LOS methodology is not designed to account for the impacts of railroad crossings on bicycle LOS.

Pedestrian LOS

The overall pedestrian level of service for an urban street is based on a combination of pedestrian density and other factors. The level of service according to density is computed. Then the pedestrian LOS according to other factors is computed. The final level of service for the facility is the worse of the two computed levels of service.

PLOS = Worse of (DPLOS, NDPLOS)   Equation 19

Where:

PLOS	= The letter grade level of service for the urban street combining density and other factors.
DPLOS	= The letter grade level of service for sidewalks, walkways and street corners based on density
NDPLOS	= The letter grade level of service for the urban street based on factors other than density

Note that the “Other-Factors” LOS will generally dominate over the “density” LOS except where the pedestrian flow rates are quite high.

The pedestrian level of service analysis is conducted separately for each side of the street, even if one side does not have a sidewalk. It is assumed that pedestrians will walk in the street in the absence of a sidewalk. Thus each street (even if a one-way street) will have two pedestrian levels of service, one for each side of the street. If pedestrians are legally barred from using one side of the street, then the pedestrian LOS for that side of the street is LOS F.

Pedestrian Density LOS (DPLOS))

The pedestrian density LOS is computed according to the method provided in Chapter 18, Pedestrians, of the Highway Capacity Manual (2000). The available sidewalk width is reduced to the effective sidewalk width according to the methods described in the Chapter 18 section “DETERMINING EFFECTIVE WALKWAY WIDTH”. The pedestrian flow rate is computed according to the section “UNINTERRUPTED-FLOW PEDESTRIAN FACILITIES” in that chapter. The pedestrian density LOS is then obtained from Exhibit 18-3 in Chapter 18 of the Highway Capacity Manual (2000). Note that the flow rates in that exhibit are per minute. Exhibit 7 below provides equivalent hourly pedestrian flow rate thresholds for level of service.

Exhibit 7: Pedestrian Density LOS (DPLOS)

LOS	Minimum Sidewalk Space Per Person	Equivalent Maximum Flow Rate per Unit Width of Sidewalk
A	> 60 SF per person	<= 300 peds/hr/ft
B	>40	<= 420
C	>24	<= 600
D	>15	<= 900
E	>8	<= 1380
F	<= 8 SF	> 1380

Adapted from Exhibit 18-3

This analysis is performed separately for each side of the street that has a sidewalk.

Pedestrian Non-Density LOS Model (Ped NDLOS)

The pedestrian LOS for the facility that is representative of non-density factors is computed according to the equation below.

NDPLOS = (0.318 PSeg + 0.220 PInt + 1.606) * (RCDF) **Equation 20**

Where

NDPLOS	= Pedestrian non-density (other factors) LOS
PSeg	= Pedestrian segment LOS value
PInt	= Pedestrian intersection LOS value
RCDF	= Roadway crossing difficulty factor

The output of this model is a numerical value, which must be translated to an LOS letter grade. Exhibit 1 above provides the numerical ranges that coincide with each LOS letter grade.

A separate pedestrian segment LOS analysis is conducted for each side of the street.

Pedestrian Segment LOS

The segment pedestrian LOS is calculated according to the following equation:**

$$PLOS = -1.2276 \ln (f_{LV} \times W_t + 0.5W_l + f_p \times \%OSP + f_b \times W_b + f_{sw} \times W_s) + 0.0091 (V/(4*PHF*L)) + 0.0004\ SPD^2 + 6.0468 \quad \text{(Equation 21)}$$

Where

Ped SegLOS = Pedestrian level of service score for a segment

ln = Natural log

f_{LV} = Low volume factor (=1.00 unless average annual daily traffic (AADT) is less than or equal to 4,000, in which case f_{LV}=(2 - 0.00025 * AADT)

W_t = total width of outside lane (and shoulder) pavement

W_l = Width of shoulder or bicycle lane, or, if there is un-striped parking and %OSP=25 then W_l=10 ft. to account for lateral displacement of traffic

f_p = On-street parking effect coefficient (=0.50)

%OSP = Percent of segment with on-street parking

f_b = Buffer area coefficient

= 5.37 for any continuous barrier at least 3 feet high separating walkway from motor vehicle traffic. A discontinuous barrier (e.g. trees, bollards, etc.) can be considered a continuous barrier if they are at least 3 feet high and are spaced 20 feet on center or less.

W_b = Buffer width (distance between edge of pavement and sidewalk, in feet)***

f_{sw} = Sidewalk presence coefficient(f_{sw}=6-0.3W_s if W_s=10, otherwise f_{sw} = 3.00)

W_s = Width of widewalk
For widths greater than 10 feet, use 10 feet.

V = Directional volume of motorized vehicles in the direction closest to the pedestrian (vph)

PHF = Peak hour factor

L = Total number of through lanes for direction of traffic closest to pedestrians.

SPD = Average running speed of motorized vehicle traffic (mi/h)

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 the traffic and the pedestrians increase the perceived separation.

Sidewalks wider than 10 feet do not further increase the perceived separation, but they do improve the pedestrian density LOS described earlier.

**This pedestrian LOS method has not been designed for nor 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. For these situations a satisfactory pedestrian level of service may not accurately reflect pedestrian perceptions.

Pedestrian Intersection LOS

The intersection LOS for pedestrians is computed only for signalized intersections according to the following equation:

Ped Int LOS (Signal) = 0.00569(RTOR+PermLefts) + 0.00013(PerpTrafVol*PerpTrafSpeed) + 0.681(LanesCrossed $^{0.514}$) + 0.0401ln(PedDelay) –RTCI(0.0027PerpTrafVol – 0.1946) + 0.5997 Equation 22

Where

RTOR+PermLefts	= Sum of the number of right-turn-on-red vehicles and the number of motorists making a permitted left turn in a 15 minute period
PerpTrafVol*PerpTrafSpeed	= Product of the traffic in the outside through lane of the street being crossed and the midblock 85th percentile speed of traffic on the street being crossed in a 15 minute period
LanesCrossed	= The number of lanes being crossed by the pedestrian
PedDelay	= Average number of seconds the pedestrian is delayed before being able to cross the intersection. If delay = zero, use 1.00 seconds.
RTCI	= Number of right turn channelization islands on the crossing. Can take on only the following values: 0, 1, or 2.

***In cases where street furniture, planter pots, and tree wells occupy the portion of the sidewalk between the pedestrians and the street (such as often occurs in central business districts with wide sidewalks), this portion of the sidewalk can be counted as a buffer strip, even though it is paved.

Roadway Crossing Difficulty Factor

The pedestrian Roadway Crossing Difficulty Factor (RCDF) measures the difficulty of crossing the street between signalized intersections. The RCDF worsens the pedestrian LOS if the crossing difficulty is worse than the non-crossing LOS for the facility. It improves the pedestrian LOS if the crossing difficulty LOS is better than the non-crossing difficulty LOS. The factor is based on the numerical difference between the crossing LOS and the non-crossing LOS. The pedestrian Roadway Crossing Difficulty Factor is limited to a maximum of 1.20 and a minimum of 0.80.

RCDF = Max[0.80, Min{[(XLOS#-NXLOS#)/7.5 + 1.00],1.20}] **Equation 23**

Where

RCDF	= Roadway crossing difficulty factor
XLOS#	= Roadway crossing difficulty LOS Number
NXLOS#	= Non-crossing Pedestrian LOS number = (0.318 PSeg + 0.220 PInt + 1.606) Pseg = Ped. Segment LOS number (computed per equation #20) Pint = Ped. Intersection LOS number (computed per equation #21)

The crossing difficulty LOS number is computed based on the minimum of the waiting-for-a-gap LOS number and diverting-to-a-signal LOS number.

XLOS = Min [WaitForGap, DivertToSignal] **Equation 24**

If it is illegal to cross the street between signalized intersections then WaitForGap is not computed. It is treated as “infinity” in equation 24.

Where:

XLOS = Crossing LOS score (based on Exhibit 8)
WaitForGap = Delay waiting for safe gap to cross.
DivertToSignal = Delay diverting to nearest signalized intersection to cross.

The delay is converted into an LOS numerical score based on the minimum of the mean delay waiting for a gap or diverting to a signal, according to the values given in Exhibit 8.

Exhibit 8. Pedestrian Crossing LOS Score

Minimum of Wait or Divert Delay (Seconds)	XLOS Score
10	1
20	2
30	3
40	4
60	5
> 60	6

Wait-For-Gap LOS Calculation

The Wait-For-Gap LOS is computed based on the expected waiting time required to find an acceptable gap in the traffic to cross the street. The acceptable gap is computed as a function of the number of lanes, their width, and the average pedestrian walking speed, with 2 seconds added.

Acceptable Gap = Crossing Distance / Pedestrian Walk Speed + 2 seconds
Equation 25

If there is adequate median refuge for pedestrians (median 6 feet wide or greater), then, at the analyst’s discretion, the shorter crossing distance to the median may be used. Otherwise the crossing distance is to the opposite curb.

The expected waiting time until an acceptable gap becomes available is computed as follows:

$$MeanWait = \frac{1}{\lambda}\left[\exp(\lambda t) - 1\right] - t$$ **Equation 26**

Where:

Mean Wait	= seconds waiting, must be greater than or equal to zero.
t	= The acceptable gap plus the time it takes for a vehicle to pass by the pedestrian. = Crossing distance/ped walk speed + vehicle pass-by time The average pass-by time = Average Vehicle Length/Average Speed, converted to seconds.
λ	= The average vehicle flow rate in vehicles per second. (If vehicle arrival rate is zero, mean wait is zero.)
Exp	= The exponential function

If there is adequate median refuge for pedestrians (median 6 feet wide or greater), then, at the analyst's discretion, the volume of traffic for only one direction of travel may be used.

If vehicle arrival rate is zero, mean wait is zero.

Divert To Signal LOS

The LOS rating for diverting to the nearest traffic signal to cross the street is computed as a function of the extra delay involved in walking to and from the mid-block crossing point to the nearest signal and the delay waiting to cross at the signal.

The geometric delay associated with diverting is the amount of time it takes the pedestrian to walk to a controlled crossing and back. To calculate this delay one must first determine the distance to nearest crossing. This distance is estimated as one-third the block length between signalized intersections. This distance is then divided by the pedestrian's walking speed (assumed to be 3.5 feet/second) to obtain the geometric delay:

Ped Geometric Delay = 2/3 * (Block Length)/Ped Walking Speed **Equation 27**

If there are no signalized intersections within the study section of the street, assume the Ped Geometric Delay is infinite. (In other words do not compute Divert to Signal Delay. Compute only wait time delay.)

The control delay at the intersection is calculated as shown below.

Ped Control Delay = (Cycle Length – Green Time)^2/(2*Cycle Length) **Equation 28**

The total delay is the sum of the two:

Total Ped Deviation Delay = Ped Geometric Delay + Ped Cycle Delay **Equation 29**

The total delay is then converted into a numerical LOS score by linearly interpolating numerical scores on the scale provided in Exhibit 8.

Computation of Facility LOS From Segment LOS

The level of service is computed separately for each direction of travel on each analysis segment.

The segment levels of service (for a given direction of travel) are combined into an overall directional level of service for the study section of street by taking a length weighted average of the segment levels of service for the analysis direction.

$$LOS(facility) = \frac{\sum LOS(i) * L(i)}{\sum L(i)}$$ **Equation 30**

Where:
LOS (facility) = LOS for subject direction of facility
LOS (segment) = LOS is subject direction for each segment (i)
L (segment) = Length of each segment (i)

Special Cases

Treatment of Sections With Significant Grades

The pedestrian level of service 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 up-grades and down-grades on pedestrian level of service. 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 manual 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 ADA Accessibility Guidelines For Buildings and Facilities (ADAAG) that apply to sidewalks and pedestrian paths/trails.

Since 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 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 Sections with Parallel Bike/Ped Path

The pedestrian LOS is estimated using the path procedures contained in Chapter 18, Pedestrians, of the Highway Capacity Manual (2000). If the analyst has information indicating that pedestrians will also walk along the street itself, then the pedestrian LOS should be computed for both the street and the path and the two results combined in the same manner as described above for bicycles using the street and using the path. The weighted average pedestrian LOS for the street is computed based on the estimated share of pedestrians using the street and the path.

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 for walking in the street.

Treatment of Gaps in Sidewalks

Segments with relatively long gaps (over 100 feet) in the sidewalk should be split into subsegments 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

If pedestrians are prohibited from walking along the street by local ordinance, then the pedestrian level of service is “F”. No pedestrian LOS computations are performed.

Treatment of Sidewalk Closures

If pedestrians are prohibited from walking along the street by a permanent sidewalk closure, then the pedestrian level of service is “F”. No pedestrian LOS computations are performed.

Treatment of Crosswalk Closures

If pedestrians are prohibited from crossing the street by a local ordinance (such as a jay-walking ordinance against mid-block crossings between signals), then the pedestrian RCDF (roadway crossing difficulty factor) is set to 1.00 and the rest of the pedestrian LOS analysis performed as normal.

If pedestrians are prohibited from crossing the subject urban street at an intersection, then the pedestrian RCDF (roadway crossing difficulty factor) is computed taking into account the extra delay to reach an alternative intersections where crossing the street is allowed.

If the crosswalk at an intersection in the direction of travel along the subject urban street is closed, then the pedestrian intersection LOS is computed adding in the extra delay necessary to cross the other 3 legs of the intersection to continue walking along the arterial.

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 on 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. The analyst may perform some tests to see if inclusion of the urban street traffic in the frontage road pedestrian LOS analyses has a significant effect on pedestrian LOS. It is possible that the urban street traffic is located so far away from the frontage road sidewalks as to have negligible effect on the pedestrian LOS.

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 Pedestrian Signals

Pedestrian signals are treated as intersections for the purpose of computing diversion delay in the RCDF computations. Pedestrian signals are ignored in the pedestrian intersection LOS computations (Pedestrians experience no delay or crossing traffic walking along the arterial at these signals). A segment with a pedestrian signal is treated in the pedestrian non-density LOS computation as a non-intersection.

Treatment of Unsignalized Mid-Block Crosswalks

The pedestrian LOS methodology is not designed to account for mid-block unsignalized crosswalks (with or without flashing warning lights).

Treatment of Railroad Crossings

The LOS methodology is not designed to account for the impacts on pedestrian LOS of railroad crossings with frequent train traffic. The analyst should determine if train frequencies and durations of crossing gate closures are low enough that their impact on pedestrian LOS can be neglected.

Treatment When Mid-Block Crossings are Illegal

The RCDF factor is computed using the divert to signal delay. The average wait time to cross the street is not computed.

Treatment of Unsignalized Intersections Including Roundabouts

The pedestrian LOS methodology does not provide for computation of pedestrian intersection LOS at unsignalized intersections. Segments with unsignalized intersections should be analyzed as if no intersections were present for the purposes of the pedestrian LOS analysis.

Treatment of Unpaved Paths/Sidewalks

The pedestrian LOS methodology is not designed to account for unpaved paths/sidewalks 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 sidewalk can be considered as almost as good as a paved sidewalk for the purpose of the pedestrian LOS computation. Otherwise the unpaved sidewalk should be considered the same as “no-sidewalk” for the purpose of pedestrian LOS computation.

Treatment of Multi-Lane Free Right Turn Lanes

Multilane free-right turn lanes may be, at times and under certain conditions, an impediment to pedestrian travel (depending on vehicle volumes, visibility, pedestrian volumes, vehicle speeds, and local enforcement). The pedestrian LOS method is not specifically designed for such situations. Should the analyst choose to compute the pedestrian LOS using the methods in this users guide, he or she should carefully evaluate the results and apply adjustments if the initial result does not appear to accurately represent the conditions present.

Treatment of High-Speed Free Right Turn Lanes

At some freeway interchanges with urban streets there may be a high-speed free right turn provided for vehicle traffic wishing to turn onto one or more of the freeway on-ramps. In such cases the on-ramp may be a significant impediment to pedestrian travel along the urban street and through the freeway interchange. The pedestrian LOS method is not specifically designed for such situations. Should the analyst choose to compute the pedestrian LOS using the methods in this users guide, he or she should carefully evaluate the results and apply adjustments if the initial result does not appear to accurately represent the conditions present.

Treatment of Bus Lanes and Bus Streets

In the case of bus streets, the pedestrian LOS is computed normally, with transit vehicles being the only motorized vehicles on the street.

In the case of bus lanes, the pedestrian LOS analysis proceeds normally. The only difference is that only transit vehicles (can carpools, if allowed) are assigned to the bus lane.

ESTIMATION OF AUTO PERFORMANCE MEASURES (SPEED, DELAY, STOPS, QUEUE)

The methodologies outlined in the Highway Capacity Manual (2000) can be used to predict average auto speed, delay, stops, and queues, when these performance measures cannot be measured in the field.

Auto Speed

The mean speed for auto traffic is computed by dividing the length of the street being evaluated by the average time it takes an automobile to travel the length of the street including all stops and delays along the way. Chapter 15, Urban Streets, of the Highway Capacity Manual (2000) describes a method for estimating the mean speed of through traffic on a street.

$$S = \frac{L}{T}$$

Equation 31

Where:
S = the mean speed (mph)
L = Length (miles)
T = Average travel time (hours)

The average travel time is equal to the travel time between intersections plus the sum of the average delay at each intersection to through traffic. The intersections may be signalized or unsignalized. They may be stop controlled or roundabouts.

$$T = \frac{L}{S_0} + \frac{1}{3600}\sum_i d_i$$

Equation 32

Where:
T = Average travel time (hours)
S_0 = posted speed limit (mph)
L = Length (miles)
d_i = Average delay for through traffic at intersection "i" (secs)

The average delay is estimated using one of the intersection analysis methods described in Chapters 16 or 17 of the Highway Capacity Manual (2000).

Auto Delay

Delay is defined as the difference between the actual travel time and the desired travel time to travel the length of the street. The desired travel time is the length of the street divided by the desired speed. The desired speed can be set by the policy of the local agency. If there is no specific local policy about the desired speed for the street, the posted speed limit can be used as the desired speed for the street.

$$D = T - \frac{L}{S_0}$$

equation 33

Where:
D = Delay (hours)
T = Average travel time (hours)
S_0 = posted speed limit (mph)
L = Length (miles)

Auto Stops

The number of stops per mile for autos can be estimated using the following equation fitted to more complex procedures developed by NCHRP 3-79 for estimating stops.

$$stops\ per\ mile = stops\ per\ vehicle\ \times L$$

$$Stops\ per\ vehicle = A1 + A2 \times \left[(x-1) + \sqrt{(x-1)^2 + A3}\right]$$

equation 34

Where:

L = length of street
X = volume/capacity ratio for through movement
A1, A2, A3 = parameters (see table below)

Exhibit 9: Parameters for Auto Stops Per Mile Equation

Signal Progression	Arrival Type	A1	A2	A3
Adverse Signal Progression	1,2	0.636	5.133	0.051
No Signal Coordination	3	0.478	6.650	0.028
Good Signal Progression	4,5,6	0.327	9.572	0.013

ESTIMATION OF TRANSIT PERFORMANCE MEASURES (SPEED, DELAY)

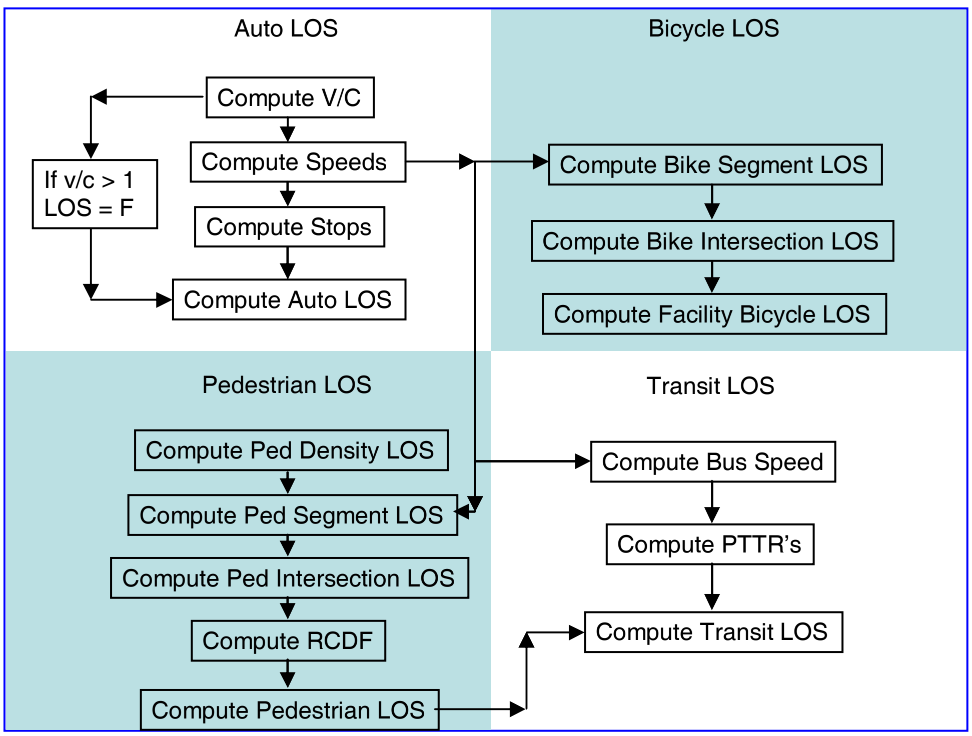
The average transit speed is best measured in the field, or using published schedules. It can be predicted using the methods described in Chapter 27 of the Highway Capacity Manual (2000).

III. APPLICATIONS

This section describes the step-by-step procedures for applying the methodology described above for estimating performance measures and level of service for urban streets. Exhibit 10 shows the general flow of the analysis. The key steps are listed below.

1. Select Analysis Method
2. Segment the Facility
3. Gather data
4. Measure or Forecast Auto Performance
5. Compute Auto LOS
6. Measure or Forecast Pedestrian Performance
7. Compute Pedestrian LOS
8. Measure or Forecast Transit Performance
9. Compute Transit LOS
10. Measure or Forecast Bicycle Performance
11. Compute Bicycle LOS

Exhibit 10: LOS Method Flow Chart



Notes:
RCDF = Roadway crossing difficulty factor
PTTR = Perceived travel time rate.

STEP 1 – SELECT ANALYSIS METHOD

For analysis of existing conditions for a facility, it is usually most accurate to measure performance in the field and then use that measured performance to compute LOS from those measurements. In this case the analyst should skip over the performance computation steps and focus only on the level of service computation steps, using their measured performance data as inputs to the LOS computations.

For planning analysis, when many design aspects of facility are not known or the subject of analysis, the analyst should perform a planning application.

When it is desired to determine the performance and quality of service provided by a specific design, the analyst should use an operations analysis.

A planning application follows the same analysis procedures as the operations analysis. The only difference is that the planning analysis substitutes local default values for less critical design and operations inputs that would normally be measured for an operations analysis.

Should the results of either the planning application or the design analysis indicate that the demand exceeds capacity of the facility for the full duration of the analysis period, then the analyst should consider either selecting a longer analysis period or switching to an alternative analysis approach employing simulation modeling.

STEP 2 – SEGMENT THE FACILITY

The **Study Length** of a street is the portion of the entire street that is selected for evaluation. The study length can be much shorter or much longer than 2 miles, as determined by the purpose of the analysis.

The study length does not necessarily need to stick to a single straight through street. The study length can follow any route that a motor vehicle can legally take. The analysis should note however, that when the study length involves a left or right turn at an intersection, the analyst must substitute data for the turn at that intersection into the computations, rather than using the straight through movement.

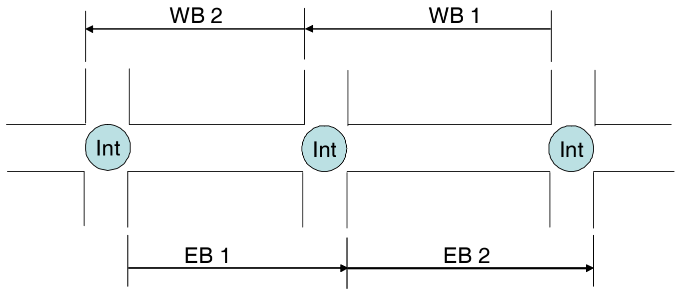
The study length is divided into **segments**. Each segment consists of a length of street between two intersections plus the downstream intersection at the end of the segment. The study length is divided into segments to ensure that the demand, control, and geometry are relatively uniform within each segment. The variation in demand, control, or geometry ideally should be greater between segments than within segments.

An **intersection** is any point on the street where through traffic is subject to signal control, stop-sign control, or yield-sign control. A signalized pedestrian cross-walk would be considered an intersection for the purposes of estimating level of service. A signalized driveway on an urban street would be considered an intersection. A roundabout on an urban street would be considered an unsignalized intersection on that street.

In addition, an intersection also occurs at any point on the urban street where another public street meets the subject street. Thus a two-way stop intersection with a public street is considered an intersection, even though through traffic on the subject street does not stop or yield.

Exhibit 11 illustrates the segmentation of a two-block long street with 3 intersections into 2 eastbound segments and 2 westbound segments. Note that each segment starts downstream of the upstream intersection and terminates downstream of the downstream intersection.

Exhibit 11: Segmentation of Facility



STEP 3 – GATHER DATA

Exhibit 12 below identifies the data required by the level of service methodology and provides suggested defaults for less critical data items.

STEP 4 – MEASURE OR FORECAST AUTO PERFORMANCE

Equations 31 and 32 are used to estimate the mean auto speed. Equation 34 is used to estimate the number of stops per mile.

STEP 5 – COMPUTE AUTO LOS

The computation of automobile level of service is performed once for each direction of vehicle travel on the street. The analysis proceeds in the following sub-steps:

a. Compute Volume/Capacity Ratio– The through movement capacity for each segment is computed at the downstream signal for each segment. The adjusted saturation flow rates (vehicles per lane per hour of green) and capacity (vehicles per hour) are computed using the procedures given in Chapter 16, Signalized Intersections of the Highway Capacity Manual (2000), as summarized below.

$$c = l * s * g / c$$

where
c = capacity (vph)
l = number of through lanes in analysis direction
s = adjusted saturation flow rate for through lane group (vphgl)
g/C = effective green time per cycle ratio for through movement

Exhibit 12. Required Data and Suggested Defaults

Street Geometry	
Number of through lanes (#)	No default
Travel lanes widths (ft),	12 feet or local default
Median width (if present) (ft)	12 feet or local default
Bike lane width (if present) (ft),	5 feet or local default
Shoulder width (if present) (ft),	No default
Parking lane width (if present) (ft),	8 feet or local default
Planter strip width (if present) (ft),	No default
Presence of barrier in planter strip (yes/no)	No default
Sidewalk width (if present) (ft)	5 feet or local default
Presence of Left Turn Lane(s) at intersections (yes/no)	No default
Length of analysis segment (ft)	No default
Presence of right turn channelization islands at intersections (yes/no)	No default
Cross-street through lanes at intersections (#)	No default
Cross-street width curb to curb (ft)	No default
Number of transit stops (#)	No default
Percent of transit stops with shelters (%)	Use local defaults
Percent of transit stops with benches (%)	Use local defaults
Unsignalized intersections and driveways (#/mile)	Use local defaults
Pavement Condition (1-5)	3 for satisfactory condition
Demand	
Intersection vehicle turning moves (vph),	No default
Vehicle right turn on red volume (vph)	No default
Vehicle peak hour factor (PHF),	0.92 or local default
Percent heavy vehicles	5% or local default
Local bus volume (vph)	No default
On-time performance of transit (%)	75% or local default
Peak passenger load factor for transit (pass/seat)	0.80 or local default
Pedestrian volume (pph)	No default
Percent of on-street parking occupied (%).	50% or local default
Intersection Control	
Saturation Flow Rate Through Lanes (vphgl)	1800 or local default
Green time per cycle for through move (g/c)	0.40 or local default
Green time per cycle for cross-street (g/c)	0.40 or local default
Cycle length (sec)	100 seconds or local default
Quality of Progression (1-5)	Use 3 for random progress.
Speed Limit (mph)	Use local defaults
Cross Street speed limit (mph)	Use local default

The through movement volume/capacity (v/c) ratio is computed for each direction of each segment. If the v/c ratio exceeds 1.00 for either direction then the segment (and the overall facility) is defined to be operating at LOS F for auto.

b. Compute Mean Through Speed – Although the automobile level of service is not dependent on the auto speed, this performance measure is required for the transit, pedestrian, and bicycle level of service analyses. The mean speed is computed using equations 31 and 32.
c. Compute Stops and Left Lanes – If one or more segments were found in the first sub-step to have v/c ratios greater than one, then this sub-step and the next can be skipped. The auto LOS is "F for the facility. Otherwise, the two required attributes for estimating auto level of service are the mean number of stops per vehicle per mile and the proportion of intersections with exclusive left turn lanes. The stops per vehicle and the number of intersections with left turn lanes are computed individually for each segment and then summed to get the facility total for the analysis direction. The number of stops per vehicle is computed for each direction of each segment using equation 34. The number of stops per vehicle is divided by the segment length to obtain average stops per vehicle per mile. The proportion of intersections with left turn lanes in the analysis direction is computed by summing the number of intersections with left turn lanes in the analysis direction and dividing by the total number of intersections.
d. Compute Auto LOS – The probability of people rating the segment according to each level of service is computed using the auto LOS cumulative logistic equation. The single letter grade level of service for each direction of each segment is computed using the special weights shown just below the table. These weights place a heavier weight on the percentage of the population that considers the street segment to operating at inferior levels of service.

STEP 6 – MEASURE OR FORECAST PEDESTRIAN PERFORMANCE

The procedures of Chapter 18, Pedestrians, of the Highway Capacity Manual (2000) are used to compute the mean speed or delay for pedestrians. Pedestrian performance data is not required to compute pedestrian level of service, so this step can be skipped if pedestrian performance results are not required.

STEP 7 – COMPUTE PEDESTRIAN LOS

The pedestrian LOS is computed next because it is a required input for the transit LOS computations.

The pedestrian LOS is computed for separately for each side of the street. If the street is two-way for vehicles, then only the flow of vehicles in one direction of travel is used in the analysis of pedestrian LOS. The direction of vehicle travel used in the pedestrian analysis is the direction of flow closest to the sidewalk (or outside curb of the street if no sidewalk) being evaluated for the pedestrian analysis. If the street is one-way for vehicle traffic, then the total vehicle flow is used in the pedestrian analysis.

The sub-steps are as follows.

a. Compute Pedestrian Density LOS – The counted (or estimated) pedestrian flow rate and sidewalk width are used to compute the pedestrian flow rate per foot width of sidewalk. The result is compared to the level of service flow rate thresholds given in

Chapter 18, Pedestrians, of the Highway Capacity Manual (2000) for sidewalks. If there is no sidewalk, this sub-step is skipped.

b. Compute Pedestrian Segment LOS – The pedestrian segment LOS is computed based on the geometry for the side of the street closest to the sidewalk (or outside curb of the street, if no sidewalk) being analyzed. Vehicle traffic volumes and speeds are obtained from the auto LOS calculation step. The average of the speed limit and the overall average auto travel speed (including delays at signals and other points) is used for the purpose of the pedestrian segment LOS computation.

c. Compute Pedestrian Intersection LOS – This computation requires additional data on the number of right turns on red (RTOR) and permitted left turns made by traffic leaving the subject street (in either the westbound or eastbound directions) and crossing the pedestrian crosswalk on the south side of the street while the “walk” indication is displayed for the crosswalk (or the signal is green, in the absence of pedestrian displays for the crosswalk). The average pedestrian delay waiting for the green light or “walk” indication at the intersection crosswalk is estimated using the procedure given in Chapter 18, Pedestrians of the Highway Capacity Manual (2000).

d. Compute Roadway Crossing Difficulty Factor (RCDF) – The analyst inputs additional information on the distance required to cross to the opposite curb for the subject street, and the green/cycle (“walk”) ratio for pedestrians crossing the subject street at the downstream signalized intersection. The “Flashing Don’t Walk” period should not be included in the computed g/c ratio for pedestrians crossing the street. If there is a median in the center of the street at least 6 feet wide, then the analyst has the option of using the walking distance to the median for the crossing distance, rather than the full curb-to-curb street width. The traffic volume used for this step includes both directions of travel on the subject street (unless a 6 foot wide median is present, in which case only traffic in the single direction closest to the sidewalk being evaluated should be used).

e. Compute Pedestrian Facility LOS – The minimum of the roadway crossing wait delay, or the divert-to-signal delay is used to compute the crossing LOS. The crossing delay is compared to the delay thresholds in Chapter 18, Pedestrians of the Highway Capacity Manual (2000), for signals to obtain the crossing LOS. The pedestrian non-density LOS is computed (without the RCDF factor) based on the previously computed segment and intersection LOS. The difference between the crossing LOS and the non-density LOS is used to determine the value of the RCDF. The RCDF multiplied by the initial non-density LOS become the final pedestrian non-density LOS. The worst of the pedestrian density and non-density LOS’s becomes the pedestrian facility LOS for each segment. The pedestrian facility LOS’s for each of the segments are averaged based on relative segment lengths, to obtain overall pedestrian facility LOS for the analysis direction.

STEP 8 – MEASURE OR FORECAST TRANSIT PERFORMANCE

The procedures of Chapter 27, Transit, of the Highway Capacity Manual (2000) are used to compute the mean speed or delay for transit. Mean transit speed is required to compute transit level of service.

STEP 9 – COMPUTE TRANSIT LOS

The transit level of service is computed separately for each direction of travel on each segment according to the following sub-steps:

a. Input Data – The frequency of transit service, on-time performance, bus stop amenities (percent with shelters, percent with benches), and load factor are entered for the subject direction for each segment. Each segment must be characterized as central business district (CBD) or not. A CBD is a segment of street where the base travel rate of bus service (against which passengers measure their perceived LOS) is 10 mph. This generally is the case for dense street networks with high-rise commercial development.
b. Compute Mean Bus Speed – The average speed of bus service is computed based on the mean auto speed and expected bus stop dwell time for each segment, following the procedure provided in Chapter 27, Transit of the Highway Capacity Manual (2000).
c. Compute Perceived Travel Time Rates – The various perceived travel time rates are computed following the formulae given in this users guide.
d. Compute Transit LOS – The transit level of service for the analysis direction of travel for each segment is computed following the formulae given in this users guide. The segment LOS results are averaged (over the analysis direction) based on relative lengths to obtain the facility LOS for the analysis direction of travel.

STEP 10 – MEASURE OR FORECAST BICYCLE PERFORMANCE

The procedures of Chapter 19, Bicycles, of the Highway Capacity Manual (2000) are used to compute the mean speed or delay for bicycles. Bicycle speed and delay data is not required to compute bicycle level of service, so this step can be skipped if bicycle performance results are not required.

STEP 11 – COMPUTE BICYCLE LOS

The bicycle LOS is computed for separately for each side of the street. If the street is two-way for vehicles, then only the flow of vehicles in one direction of travel is used in the analysis of bicycle LOS. The direction of vehicle travel used in the bicycle analysis is the direction of flow closest to the sidewalk (or outside curb of the street if no sidewalk) being evaluated for the pedestrian analysis. If the street is one-way for vehicle traffic, then the total vehicle flow is used in the bicycle analysis.

The sub-steps are as follows.

a. Performance and Other Input Data – The auto volumes and speed are obtained from the auto LOS analysis. The on-street parking percentage is the same as was used in the pedestrian analysis. The percent heavy vehicles and the pavement rating are new data items required for the bicycle LOS analysis.
b. Compute Bicycle LOS – The effective width (between the bicyclist and vehicle traffic) is computed first based upon the vehicle volume and then based on other factors to obtain the final “effective width”. The mean vehicle speed is converted to a “speed factor” (The speed factor is fixed at 0.8103 for vehicle speeds less than 21 mph). The segment, intersection, and combined bicycle LOS for each segment are computed using the formulae given in this users guide. The length weighted average bicycle LOS for the analysis direction of the facility is computed based on the relative segment lengths.

IV. ACCURACY AND SENSITIVITIES

This section provides information on the sensitivity of the estimated multimodal level of service to key input variables. This section provides information on the confidence intervals for the predicted level of service.

MULTIMODAL LOS METHOD

The procedures in this users guide for estimating multimodal level of service on an urban street are directly sensitive to the variables listed below:

- Auto LOS: left turn lane presence, Stops per mile (which are in turn sensitive to facility geometry and control factors)
- Transit LOS: Frequency of service, mean speed, reliability of service, load factors, quality of pedestrian access to transit stops.
- Bicycle LOS: lateral separation between bicycles and vehicular traffic, speed and makeup of vehicle traffic, pavement condition.
- Pedestrian LOS: Lateral separation between pedestrians and vehicular traffic, width of sidewalk, speed and makeup of vehicle traffic, difficulty of crossing arterial.

The procedures for estimating modal level of service on an urban street are able to predict the mean of the traveler perceived level of service for the facility within the confidence intervals given in Exhibit 13 (given that no default inputs are used):

Exhibit 13. Confidence Interval for Modal LOS Estimates

Mode of Travel	Confidence Interval of Predicted Mean LOS
Auto LOS	+/- One LOS letter grade, 94% of time
Transit LOS	+/- One LOS letter grade, 71% of time
Bicycle LOS	+/- One LOS letter grade, 85% of time
Pedestrian LOS	+/- One LOS letter grade, 86% of time

Field Measurement of LOS versus Estimation using HCM

Field measurement of travelers' perceived satisfaction with the quality of service is not recommended, because it will tend to be biased. Travelers dissatisfied with the service will tend to be under represented on the facility (If they don't like it, they won't use it). Infrequent users or non-users of a given mode may have different priorities than frequent users and may therefore rate the facility and its conditions quite differently. The preferred method to directly measure level of service is to show the facility conditions to a group of people via video or otherwise and ask them to rate the facility on a letter grade range from "A" to "F" with "A" representing "The Best", and "F" representing "The Worst".

Implications of Using Default Values for Selected Inputs

The use of default values in lieu of measured inputs will tend to adversely affect the accuracy of the predicted level of service. However, there are many situations (such as evaluating a proposed facility that does not yet exist) where it is impossible to measure all of the required and assumed values must be used. Default values can also be used where the sensitivity of the predicted LOS to variations in the value is low and where the implications of errors in the predicted LOS are low (for example, the difference in predicted LOS is between LOS "A" and LOS "B").

V. FACILITY PLANNING/DESIGN AIDS

This section provides an example set of service volume look-up tables for quickly estimating the basic facility design parameters (number of lanes, right of way, medians, multimodal features, signal spacing, etc.) required to achieve a target multimodal level of service for forecasted modal demand levels. Other service volume tables should be constructed based on assumptions more appropriate to each locality.

Exhibit 14: AADT Auto Service Volume Table, below provides the maximum daily vehicle traffic service volumes for representative street cross-sections (number of through lanes and exclusive left turn lanes), and representative control types (signal spacing and progression). Table entries are the maximum AADT that can be accommodated without exceeding the target level of service for auto.

Exhibit 15: AADT Auto Service Volume Table for Bus LOS, below provides the maximum daily vehicle traffic service volumes for representative street cross-sections (number of through lanes), bus service levels (frequencies), and bus stop amenities (proportion of stops with shelters). Table entries are the maximum AADT that can be accommodated without exceeding the target level of service for bus. In many cases the auto volume would have to exceed the peak 15-minute capacity of the facility (expressed in the table in terms of the equivalent AADT) before the bus LOS would deteriorate to a worse level.

Exhibit 16: AADT Auto Service Volume Table for Bicycle LOS, below provides the maximum daily vehicle traffic service volumes for representative street cross-sections (number of through lanes with and without bike lanes), and facility posted speed limit. Table entries are the maximum AADT that can be accommodated without exceeding the target level of service for bicycles. In many cases the auto volume would have to exceed the peak 15-minute capacity of the facility (expressed in the table in terms of the equivalent AADT) before the bicycle LOS would deteriorate to a worse level.

Exhibit 17: AADT Auto Service Volume Table for Pedestrian LOS, below provides the maximum daily vehicle traffic service volumes for representative street cross-sections (number of through lanes with and without on-street parking and landscaped tree buffer strips), and facility posted speed limit. Table entries are the maximum AADT that can be accommodated without exceeding the target level of service for pedestrians. In many cases the auto volume would have to exceed the peak 15-minute capacity of the facility (expressed in the table in terms of the equivalent AADT) before the pedestrian LOS would deteriorate to a worse level.

The default values for various input parameters necessary for the LOS computations are listed below each table.

Exhibit 14: AADT Auto Service Volume Table for Auto LOS

Two-Way	Signal	Signal	Left Turn	Max. AADT For Auto LOS		
Lanes	Spacing (ft)	Progress.	Lanes	C	D	E
2	500	None	No	4,000	11,800	13,500
2	500	None	Yes	9,200	12,500	13,800
2	500	Good	No	11,200	13,200	> 14,000
2	500	Good	Yes	12,200	13,500	> 14,000
2	1320	None	No	> 14,000	> 14,000	> 14,000
2	1320	None	Yes	> 14,000	> 14,000	> 14,000
2	>=2640	None	Yes & No	> 14,000	> 14,000	> 14,000
4	500	None	No	8,000	23,700	27,000
4	500	None	Yes	18,400	25,100	27,600
4	500	Good	No	22,500	26,400	> 28,000
4	500	Good	Yes	24,500	27,000	> 28,000
4	1320	None	No	> 28,000	> 28,000	> 28,000
4	1320	None	Yes	> 28,000	> 28,000	> 28,000
4	>=2640	None	Yes & No	> 28,000	> 28,000	> 28,000
6	500	None	No	12,000	35,500	40,500
6	500	None	Yes	27,600	37,600	41,400
6	500	Good	No	33,700	39,600	> 42,000
6	500	Good	Yes	36,800	40,500	> 42,000
6	1320	None	No	> 42,000	> 42,000	> 42,000
6	1320	None	Yes	> 42,000	> 42,000	> 42,000
6	>=2640	None	Yes & No	> 42,000	> 42,000	> 42,000

N/A = LOS not achievable for given configuration and default values.
> XXX means capacity of street exceeded before LOS exceeded.

Default Values	
Peaking Factor (K)	0.09
Directional Factor (D)	0.55
Peak Hr. Fac. (PHF)	0.92
Adj. Sat Flow (vphgl)	1800
Through g/c	0.42
Cycle Length (sec)	100

Exhibit 15: AADT Auto Service Volume Table for Bus LOS

Two-Way Lanes	Bus Frq. bus/hr	Shelters (%)	Max. Auto AADT For Bus LOS C	D	E
2	1	0%	N/A	N/A	N/A
2	1	100%	N/A	N/A	N/A
2	2	0%	N/A	13600	>14000
2	2	100%	N/A	13800	>14000
2	4	0%	>14000	>14000	>14000
2	>= 4	100%	>14000	>14000	>14000
4	1	0%	N/A	N/A	N/A
4	1	100%	N/A	N/A	N/A
4	2	0%	N/A	27700	>28000
4	2	100%	N/A	>28000	>28000
4	>= 4	0%-100%	>28000	>28000	>28000
6	1	0%	N/A	N/A	N/A
6	1	100%	N/A	N/A	N/A
6	2	0%	N/A	41900	>42000
6	2	100%	N/A	>42000	>42000
6	>= 4	0%-100%	>42000	>42000	>42000

N/A = LOS not achievable for given configuration and default values.
>000 = auto volumes would have to exceed capacity to cause bus LOS to deteriorate further

Auto Defaults	
Peaking Factor (K)	0.09
Directional Factor (D)	0.55
Peak Hr. Fac. (PHF)	0.92
Adj. Sat Flow (vphgl)	1800
Through g/c	0.42
Cycle Length (sec)	100
Signal Spacing (ft)	1320
Progression Quality	3
Posted Speed (mph)	45

Pedestrian Defaults	
% Parking Occ.	50%
Barrier (Yes/No)	No
RTOR+Perm LT (vph)	50
X-Street Vol. (vph)	1500
X-Street Speed (mph)	35
X-Street Lanes (#)	5
Right Turn Islands (#)	2
X-Street Walk g/c	0.10
Sidewalk Width (ft)	5

Transit LOS Inputs	
% On Time	85%
% Stops w. Benches	50%
Load Factor (p/seat)	1.00
CBD (Yes/No)	Yes
Bus Stops/segment	1
Delay/Bus Stop (sec)	20

Exhibit 16: AADT Auto Service Volume Table for Bicycle LOS

Two-Way	Speed Lim	Bike	Max. Auto AADT For Bike LOS		
Lanes	(mph)	Lane	C	D	E
2	25	No	2100	>14000	>14000
2	25	Yes	6800	>14000	>14000
2	35	No	1600	8600	>14000
2	35	Yes	2900	>14000	>14000
2	45	No	1500	5200	>14000
2	45	Yes	2900	>14000	>14000
4	25	No	2200	>28000	>28000
4	25	Yes	13700	>28000	>28000
4	35	No	1800	16800	>28000
4	35	Yes	2900	>28000	>28000
4	45	No	1600	10300	>28000
4	45	Yes	2900	>28000	>28000
6	25	No	2300	>42000	>42000
6	25	Yes	20500	>42000	>42000
6	35	No	1800	25100	>42000
6	35	Yes	2900	>42000	>42000
6	45	No	1700	15400	>42000
6	45	Yes	2900	>42000	>42000

N/A = LOS not achievable for given configuration and default values.
>000 = auto volumes would have to exceed capacity to cause bike LOS to deteriorate further

Auto Defaults	
Peaking Factor (K)	0.09
Directional Factor (D)	0.55
Peak Hr. Fac. (PHF)	0.92
Adj. Sat Flow (vphgl)	1800
Through g/c	0.42
Cycle Length (sec)	100
Signal Spacing (ft)	1320
Progression Quality	3

Bicycle Defaults	
% Parking Occ.	50%
Unsig Conflicts/Mile	10
Bike Lane Width (ft)	5
Parking Lane	Yes

Exhibit 17: AADT Auto Service Volume Table for Pedestrian LOS

Two-Way Lanes	On-Street Parking	Tree Buffer Strip	Speed Lim (mph)	Max. Auto AADT For Ped LOS C	D	E
2	Yes	No	25-45	4,400	5,600	10,800
2	No	No	25-45	5,500	10,100	11,400
2	Yes	Yes	25-45	4,400	6,400	>14000
2	No	Yes	25-45	8,200	10,100	>14000
4	No	No	45	3,500	4,500	13,900
4	No	No	35	3,500	4,500	16,100
4	No	No	25	3,500	4,400	17,900
4	Yes	No	45	2,300	3,000	17,800
4	Yes	No	35	2,300	3,000	19,900
4	Yes	No	25	2,300	3,300	21,700
4	Yes	Yes	45	2,300	3,600	>28,000
4	Yes	Yes	35	2,300	3,600	>28,000
4	Yes	Yes	25	2,300	5,500	>28,000
4	No	Yes	45	3,500	5,300	>28,000
4	No	Yes	35	3,500	5,200	>28,000
4	No	Yes	25	3,500	5,100	>28,000
6	No	No	45	1,900	2,600	20,800
6	No	No	35	1,900	2,500	24,200
6	No	No	25	1,900	2,500	26,900
6	Yes	No	45	1,400	1,900	26,600
6	Yes	No	35	1,400	2,000	29,900
6	Yes	No	25	1,400	2,200	32,500
6	No	Yes	45	1,900	3,000	>42000
6	No	Yes	35	1,900	3,000	>42000
6	No	Yes	25	1,900	5,700	>42000
6	Yes	Yes	45	1,400	2,300	>42000
6	Yes	Yes	35	1,400	5,400	>42000
6	Yes	Yes	25	1,400	8,300	>42000

N/A = LOS not achievable for given configuration and default values.
>000 = auto volumes would have to exceed capacity to cause ped LOS to deteriorate further
Note: this table assumes street is narrower by 16 feet if No-Parking.

Auto Defaults	
Peaking Factor (K)	0.09
Directional Factor (D)	0.55
Peak Hr. Fac. (PHF)	0.92
Adj. Sat Flow (vphgl)	1800
Through g/c	0.42
Cycle Length (sec)	100
Signal Spacing (ft)	1320
Progression Quality	3
Posted Speed (mph)	45

Pedestrian Defaults	
% Parking Occ.	50%
Barrier (Yes/No)	Yes
RTOR+Per.LT (vph)	50
X-Street Vol. (vph)	1500
X-Street Spd (mph)	35
X-Street Lanes (#)	5
Right Turn Islnds (#)	2
X-Street Walk g/c	0.10
Sidewalk Width (ft)	5
Planter Strip (Ft)	8
Ped Flow (pph)	60

VI. EXAMPLE PROBLEMS

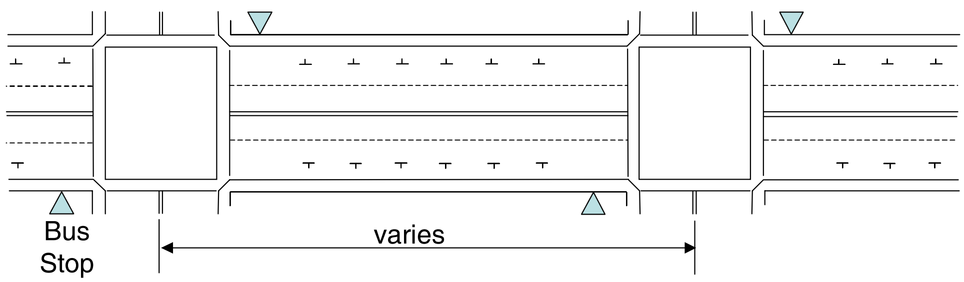
This section provides example problems illustrating the application of the above described methodologies for estimating the performance and level of service for urban streets.

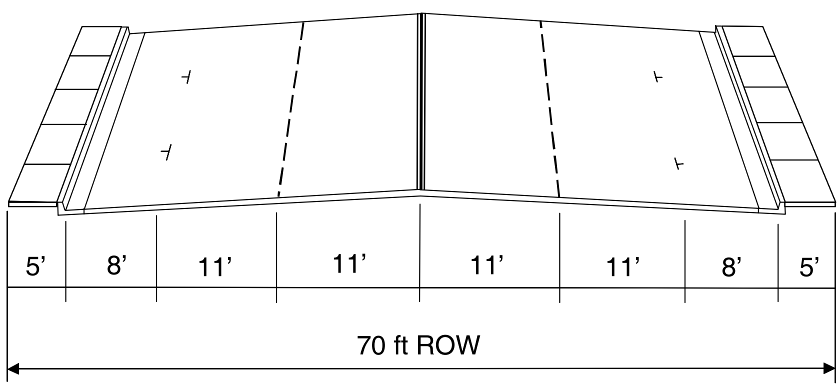
EXAMPLE PROBLEM 1 – DETERMINE LOS OF STREET

Objective: To determine the perceived level of service (LOS) for all modal users of the urban street with a given configuration and demand.

Data: The study length of the urban street is 1 mile long. Within this study section, the street is generally a 4 lane arterial with parking and sidewalk (see below). Traffic signals are present at each intersection. The street carries between 10,000 and 15,000 average annual daily traffic (AADT). The specific segment data

Exhibit 18. Example Problem 1 Plan and Cross-section





Key Issues: This sample problem illustrates the computation of level of service for a given street design and a given demand level.

Approach:

1. Determine starting and ending points of study section of street. –For convenience, the beginning intersection for each direction of analysis will be excluded from the directional analysis (this causes the analysis procedure for each segment to be identical, only with different data for each segment).
2. Start evaluation of LOS for the Eastbound Direction.
3. Divvy up Eastbound Study Section into Analysis Segments – Since the demand varies between intersections, while the geometry is constant the length of the facility, the facility is divided into 5 segments. Each analysis segment is defined to start immediately

downstream of the beginning traffic signal and to end immediately downstream of the ending traffic signal. Thus, each analysis segment consists of a segment and a traffic signal.

4. Assemble Data – The required data is shown for each segment in the exhibits.
5. Compute Auto LOS – The required inputs and computation results are shown in Exhibit 19: Example 1 - Computation of Auto LOS. The analysis begins with the eastbound direction (Since the procedures for evaluating the westbound direction are identical, they are not shown here in this example problem).
   a. Compute Demand - The eastbound hourly flow rate for the peak 15 minutes of the weekday peak hour is computed by applying a peaking factor (k), a directional factor (d), and a peak hour factor (PHF) to the average weekday traffic for each segment. This step can be skipped if peak 15 minute flow rates are available.
   b. Compute Capacity – The eastbound through movement capacity for each segment is computed at the downstream signal for each segment. The adjusted saturation flow rate (vehicles per lane per hour of green) are computed using the procedures given in Chapter 16, Signalized Intersections of the Highway Capacity Manual (2000). The volume/capacity (v/c) ratio is computed for each segment. If the v/c ratio exceeds 1.00 then the segment is defined to be operating at LOS F.
   c. Compute Mean Through Speed – Although the automobile level of service is not dependent on the auto speed, this piece of information is required for the transit, pedestrian, and bicycle level of service analyses. The mean speed is computed using equations 31 and 32.
   d. Compute Stops and Left Lanes – The two required pieces of information for estimating auto level of service are the mean number of stops per vehicle per mile and the proportion of intersections with exclusive left turn lanes. The number of stops per vehicle is computed for each segment using equation 34. The number of stops per vehicle is divided by the segment length to obtain average stops per vehicle per mile. The proportion of intersections with left turn lanes is computed by summing the number of intersections with left turn lanes in the eastbound direction and dividing by the total number of intersections.
   e. Compute Auto LOS – The probability of people rating the segment according to each level of service is computed using the auto LOS model. The average level of service for each segment is computed using the special weights shown just below the table. These weights place a heavier weight on the percentage of the population that considers the street segment to operating at inferior levels of service. Once the segment LOS values are known, they are used to compute the average level of service for the eastbound direction of the street by weighting the LOS results for each segment by the relative length of each segment within the study section.

6. Compute Pedestrian LOS – The pedestrian LOS is computed next because it is a required input for the transit LOS. The pedestrian LOS is computed for pedestrian travel on the right-hand side of the eastbound direction of auto travel for the street. The computations are shown in Exhibit 20: Example 1 - Computation of Pedestrian LOS.
    a. Compute Pedestrian Density LOS – The counted (or estimated) pedestrian flow rate and sidewalk width are used to compute the pedestrian flow rate per foot width of sidewalk. The result is compared to the level of service flow rate thresholds given in Chapter 18, Pedestrians, of the Highway Capacity Manual (2000), for sidewalks. If there is no sidewalk, this step is skipped.
    b. Compute Pedestrian Segment LOS – The pedestrian segment LOS is computed based on the geometry for the right-hand side of the street looking in the eastbound direction. Vehicle traffic volumes and speeds are obtained from the auto LOS calculation step. The average of the mid-block free-flow speed and the overall average auto travel speed is used for the purpose of the pedestrian segment LOS computation.
    c. Compute Pedestrian Intersection LOS – This computation requires additional data on the number of right turns on red (RTOR) and permitted left turns made by traffic leaving the subject street (in either the westbound or eastbound directions) and crossing the pedestrian crosswalk on the south side of the street while the "walk" indication is displayed for the crosswalk (or the signal is green, in the absence of pedestrian displays for the crosswalk). The average pedestrian delay waiting for the green light or "walk" indication at the intersection crosswalk is estimated using the procedure given in Chapter 18, Pedestrians of the Highway Capacity Manual (2000).
    d. Compute Roadway Crossing Difficulty Factor (RCDF) – The analyst inputs additional information on the distance required to cross to the opposite curb for the subject street, and the green/cycle ("walk") ratio for pedestrians crossing the subject street at the downstream signalized intersection. The "Flashing Don't Walk" period should not be included in the computed g/c ratio for pedestrians crossing the street. If there is a median in the center of the street at least 6 feet wide, then the walking distance to the median can be used for the crossing distance, rather than the full curb-to-curb street width. The traffic volume used for this step includes both direction of travel on the subject street (unless a wide median is present, in which case only traffic in the eastbound direction should be used).
    e. Compute Pedestrian Facility LOS – The minimum of the roadway crossing wait delay, or the divert to signal delay is used to computed the crossing LOS. The crossing delay is compared delay thresholds in Chapter 18, Pedestrians, of the Highway Capacity Manual (2000), to obtain the crossing LOS. The pedestrian non-density LOS is computed (without the RCDF factor) based on the previously computed segment and intersection LOS. The difference between these the crossing LOS and the non-density LOS is used to determine the value of the RCDF. The RCDF multiplied by the initial non-density LOS become the final pedestrian non-density LOS. The worst of the pedestrian density and non-density LOS's becomes the pedestrian facility LOS for each segment. The pedestrian facility LOS's for each of the segments are averaged based on relative segment lengths, to obtain overall pedestrian facility LOS for the eastbound direction.

7. Compute Transit LOS – The data and computation steps are shown in Exhibit 21: Example 1 - Computation of Transit LOS.
   a. Input Data – The frequency of transit service, on-time performance, bus stop amenities (percent with shelters, percent with benches), and load factor are entered for the eastbound direction for each segment. Each segment must be characterized as central business district (CBD) or not. A CBD is a segment of street where the base travel rate of bus service (against which passengers measure their perceived LOS) is 15 mph. This generally is the case for dense street networks with high rise development.
   b. Compute Mean Bus Speed – The average speed of bus service is computed based on the mean auto speed and expected bus stop dwell time for each segment, following the procedure provided in Chapter 27, Transit of the Highway Capacity Manual (2000).
   c. Compute Perceived Travel Time Rates – The various perceived travel time rates are computed following the formulae given in this users guide.
   d. Compute Transit LOS – The transit level of service for the eastbound direction of travel for each segment is computed following the formulae given in this users guide. The segment LOS results are averaged based on relative lengths to obtain the facility LOS for the eastbound direction of travel.
8. Compute Bicycle LOS
   a. Geometric Input Data – Much of the same geometric input data required for the auto and pedestrian LOS analyses are used for the bicycle LOS analysis. New data items consist of whether or not the street has a median (is divided), the width of cross-streets, and the number of unsignalized intersections and major driveways per mile.
   b. Performance and Other Input Data – The auto volumes and speed are obtained from the auto LOS analysis. The on-street parking percentage is the same as was used in the pedestrian analysis. The percent heavy vehicles and the pavement rating are new data items required for the bicycle LOS analysis.
   c. Compute Bicycle LOS – The effective width (between the bicyclist and vehicle traffic) is computed first based upon the vehicle volume and then based on other factors to obtain the final "effective width". The mean vehicle speed is converted to a "speed factor" (The speed factor is fixed at 0.8103 for vehicle speeds less than 21 mph). Note that the parking lane is treated as a shoulder lane (for bicycle LOS computation purposes) only in segment #5 where the parking occupancy is 0%. The segment, intersection, and combined bicycle LOS for each segment are computed using the formulae given in this users guide. The length weighted average bicycle LOS for the eastbound direction of the facility is computed based on the relative segment lengths.
9. Summary Table of LOS Results – The summary table of modal LOS results is given in Exhibit 23: Example 1 – Summary of Results
10. The above analysis is then repeated for the reverse direction of travel on the street.

Exhibit 19: Example 1 - Computation of Auto LOS

1. Compute Eastbound Hourly Demand (v)

Segment	Weekday ADT (vpd)	Peak Factor k (#)	Dir. Factor d (#)	Pk.Hr.Fac. PHF (#)	Demand v (vph)
1	10,000	0.080	0.55	0.92	478
2	15,000	0.080	0.55	0.92	717
3	10,000	0.080	0.55	0.92	478
4	15,000	0.080	0.55	0.92	717
5	10,000	0.080	0.55	0.92	478

2. Compute Eastbound Hourly Capacity and V/C

Segment	Adjusted Saturation (vphgl)	Thru Lanes One-Dir. (#)	Thru (g/C) (#)	Capacity (vph)	V/c	V/c Check
1	1500	2	0.50	1500	0.32	OK
2	1500	2	0.50	1500	0.48	OK
3	1650	2	0.45	1485	0.32	OK
4	1650	2	0.45	1485	0.48	OK
5	1650	2	0.44	1452	0.33	OK

Adjusted Sat. Flows computed per Chapter 16, Signalized Intersections.

3. Compute Mean Through Speed

Segment	Free Speed (mph)	Segment Length (ft)	Cycle Length (sec)	Progress. Quality (#)	Intersect Delay (sec)	Average Speed (mph)
1	35	600	60	5	3.5	26.9
2	35	600	60	5	4.2	25.7
3	35	1200	90	3	16.5	20.5
4	35	1200	120	3	24.2	17.2
5	35	1680	120	3	22.6	20.7
Total/Ave.		5280				20.7

4. Compute Stops & % Left Lane

Segment	Progress. Quality (#)	Stops Per Veh. (stps/veh)	Segment Length (ft)	Stops Per Mile (stps/mi)	Left Ln (Yes=1) (0,1)
1	5	0.41	600	3.65	0
2	5	0.44	600	3.88	0
3	3	0.61	1200	2.71	0
4	3	0.66	1200	2.88	0
5	3	0.62	1680	1.94	0
Total/Ave		2.74	5280	2.74	0.00

5. Compute Auto LOS

Segment	LOS A (%)	LOS B (%)	LOS C (%)	LOS D (%)	LOS E (%)	LOS F (%)	Weight. Ave.	Auto LOS
1	11.1%	31.5%	26.8%	16.2%	9.1%	5.3%	2.97	C
2	10.5%	30.7%	26.9%	16.8%	9.5%	5.6%	3.01	C
3	13.6%	34.8%	25.7%	14.1%	7.5%	4.2%	2.80	C
4	13.1%	34.2%	25.9%	14.5%	7.8%	4.4%	2.83	C
5	16.1%	37.2%	24.4%	12.4%	6.3%	3.5%	2.66	B
Average	13.5%	34.7%	25.7%	14.2%	7.5%	4.3%	2.80	C
weights:	1	2	3	4	5	6		

Exhibit 20: Example 1 - Computation of Pedestrian LOS

1. Compute Pedestrian Density LOS

Seg.	Sidewalk Width (ft)	Ped Flow (pph)	Ped. Density LOS #	Ped. Density LOS
1	5	4000	4.12	D
2	5	1500	1.84	B
3	5	1000	1.27	A
4	5	500	0.65	A
5	5	50	0.07	A

Density LOS Lookup	
Ped/hr/ft	LOS
0	A
300	B
420	C
600	D
900	E
1380	F

2. Compute Pedestrian Segment LOS

Seg.	Outside Lane (ft)	Bike/Shlder Lane Width (ft)	On-Street Parking (%)	Barrier (Y/N)	Buffer Width (ft)	Dir. Traffic Volume (vph)	Traf. Lnes One-Dir (lanes)	Midblock Traf Spd (mph)	Ped. Seg. LOS #
1	12	8	100%	No	0	478	2	31.0	1.97
2	12	8	50%	No	0	717	2	30.3	2.48
3	12	8	25%	No	0	478	2	27.8	2.24
4	12	8	25%	No	0	717	2	26.1	2.51
5	12	8	5%	No	0	478	2	27.9	2.35

Midblock traffic speed = average of auto free-flow speed, and mean auto speed with intersection delay.

3. Compute Pedestrian Intersection LOS

Seg.	RTOR+ Perm LT (vph)	X-Street Volume (vph)	X-Street PHF (#)	X-Street Speed (mph)	X-Street Lanes (#)	Ped. Delay (sec)	Right Trn Channel Islands (#)	Ped. Intersect LOS #
1	50	500	0.92	25	2	7.5	0	2.48
2	75	500	0.92	25	2	7.5	0	2.52
3	50	750	0.92	35	4	13.6	0	3.03
4	50	1200	0.92	40	4	18.2	2	4.12
5	50	1500	0.92	45	6	18.8	2	4.85

Pedestrian Delay computed per Chapter 18 method.

4. Compute Roadway Crossing Difficulty Factor (RCDF)

Seg.	Signal Spacing (ft)	Signal Cycle (sec)	Cross St. g/C (#)	Divert Delay (sec)	Crossing Distance (ft)	Vehicle Speed (mph)	Vehicle Vol 2-Dir (vph)	Ave. Wait (sec)
1	600	60	0.17	135	64	31.0	800	421
2	600	60	0.17	135	64	30.3	1,200	2943
3	1200	90	0.11	264	64	27.8	800	425
4	1200	120	0.08	279	64	26.1	1,200	3009
5	1680	120	0.08	370	64	27.9	800	425

5. Compute Pedestrian Facility LOS

Seg.	Min. Wait,Divrt (sec)	Crossing LOS (#)	No Cross LOS (#)	RCDF (#)	Ped. NDLOS (#)	Ped. Density LOS #	Ped. Fac. LOS (#)	Ped. Facility LOS
1	135	6.00	2.78	1.20	3.33	4.12	4.12	E
2	135	6.00	2.95	1.20	3.54	1.84	3.54	E
3	264	6.00	2.98	1.20	3.58	1.27	3.58	E
4	279	6.00	3.31	1.20	3.97	0.65	3.97	E
5	370	6.00	3.42	1.20	4.10	0.07	4.10	E
Ave							3.89	E

Exhibit 21: Example 1 - Computation of Transit LOS

1. Input Data

Segment	Transit Frequency (bus/h)	On-Time Performance (%)	Stops with Shelter (%)	Stops with Bench (%)	Load Factor (p/seat)	Central Busi. District (Y/N)
1	18	48%	100%	100%	1.1	Yes
2	18	48%	100%	100%	1.2	Yes
3	9	50%	0%	100%	0.8	No
4	4	65%	0%	0%	0.7	No
5	2	70%	0%	0%	0.5	No

2. Compute Mean Bus Speed

Segment	Length (ft)	Auto Spd (mph)	Bus Stops (#)	Delay/Stop (sec)	Ave Bus (mph)
1	600	26.9	1	20	11.6
2	600	25.7	1	20	11.4
3	1200	20.5	1	15	14.9
4	1200	17.2	1	15	13.1
5	1680	20.7	1	10	17.5
Total/Ave	5280	20.7			14.2

Average Bus Speed computed per Chapter 27 method.

3. Compute Transit Perceived Travel Time and Headway Factors

Segment	a1 factor	IVTTR min/mi	EWTTR min/mi	ATR min/mi	PTTR	Fptt	Fh
1	1.41	5.16	1.83	0.41	10.52	0.70	3.75
2	1.60	5.27	1.83	0.41	11.66	0.67	3.75
3	1.00	4.02	1.69	0.05	7.35	0.92	3.46
4	1.00	4.59	0.83	0.00	6.24	0.98	2.83
5	1.00	3.42	0.61	0.00	4.64	1.11	1.97

IVTTR = In-Vehicle Travel Time Rate
EWTTR = Equivalent Wait Travel Time Rate
ATR = Amenity Time Rate
PTTR = Perceived Travel Time Rate
Fptt = Perceived Travel Time Factor
Fh = Headway Factor

4. Compute Transit LOS

Segment	Wait/Ride Score	Ped LOS	LOS Score	Transit LOS
1	2.61	4.12	2.71	B
2	2.52	3.54	2.75	B
3	3.19	3.58	1.75	A
4	2.79	3.97	2.42	B
5	2.19	4.10	3.34	C
Average			2.63	B

Note: Shaded entries are input data fields

Exhibit 22: Example 1 - Computation of Bicycle LOS

1. Geometric Input Data

Segment	Outside Lane Width (ft)	Bike/Shldr Lane Width (ft)	Through Lanes (lanes)	Divided/ Undivided (D/UD)	Sig. Int Cross-Dist (ft)	Unsig. Conf Per Mile (conf/mi)
1	12	0	2	UD	40	0.0
2	12	0	2	UD	40	10.0
3	12	0	2	UD	64	5.0
4	12	0	2	UD	64	2.0
5	12	0	2	UD	88	1.0

2. Performance and Other Input Data

Segment	Traffic Volume (vph)	Heavy Vehicle (%)	Midblock Traffic Spd (mph)	On-Street Parking (%)	Pavement Rating (#)
1	478	3%	31.0	100%	4.0
2	717	6%	30.3	50%	4.0
3	478	12%	27.8	25%	3.5
4	717	12%	26.1	25%	4.0
5	478	6%	27.9	5%	4.0

Pavement Rating: 1=Poor, 5=Excellent

Midblock traffic speed = average of auto free-flow speed and mean auto speed with intersection delay.

3. Compute Bicycle LOS

Segment	Prelim. Eff. Width (Wv)	Effective Width (We)	Speed Factor (#)	Segment LOS (#)	Intersect LOS (#)	Bicycle Score (#)	Bike LOS
1	12.0	2.0	3.49	4.52	2.62	3.72	E
2	12.0	7.0	3.43	5.10	2.85	4.21	E
3	12.0	9.5	3.11	6.14	2.99	4.23	E
4	12.0	9.5	2.84	5.94	3.21	4.14	E
5	12.0	11.5	3.12	4.32	3.36	3.89	E
Average						4.04	E

Note: Shaded entries are input data fields

Exhibit 23: Example 1 – Summary of Results

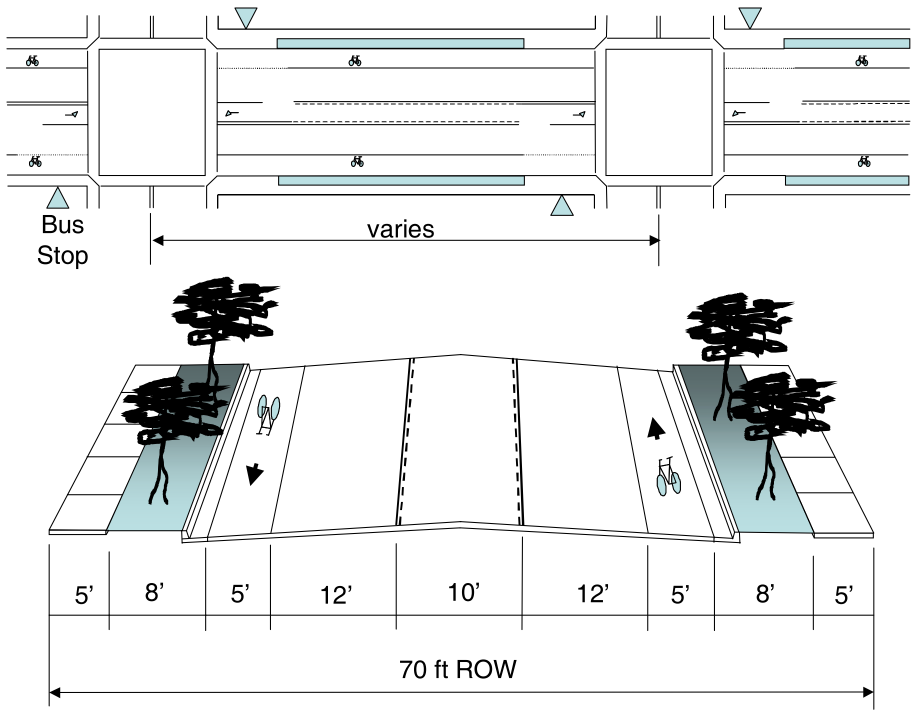
Direction =	Eastbound

Segment	Auto LOS	Transit LOS	Bicycle LOS	Pedestrian LOS
1	C	B	E	E
2	C	B	E	E
3	C	A	E	E
4	C	B	E	E
5	B	C	E	E
Facility	C	B	E	E

EXAMPLE PROBLEM 2 – DETERMINE LOS IMPACTS OF CONVERTING FROM 4-LANE TO 3-LANE CROSS-SECTION

Objective: For a given set of modal demands, determine the impacts of converting a street from 4 auto lanes to 2 lanes plus two-way-left-turn-lane.

Exhibit 24: Example Problem 3 Plan and Cross-Section Views



Key Issues: The key issue in this example is the tradeoff between the benefits to the bicycles of providing the bicycle lane and the reduction of through lanes for autos and buses from 4 lanes to 2 lanes plus a two-way left turn lane. Since this configuration puts more vehicle traffic closer to the sidewalk (by concentrating two-lanes worth of traffic into a single lane in each direction), a 5-foot wide landscaped buffer strip with trees has been added between the curb and the sidewalk to mitigate this potential impact. The parking lanes on both sides were eliminated on both sides to make room for the landscaped buffer strips. The addition of bicycle lanes benefits bicyclists, however; the concentration of all vehicle traffic in a single lane in each direction, closer to bicyclists, is a disbenefit for them. A level of service analysis is required to see if the proposed new cross-section has a positive, negative, or neutral impact on auto drivers, transit passengers, bicyclists and pedestrians.

Approach: The same analysis approach is used as was used in Example Problem #1. The points below highlight the changes in the inputs and results.

1. Determine starting and ending points of study section of street. – Use the same limits as for Example Problem 1.
2. Start evaluation of LOS for the Eastbound Direction.
3. Divvy up Eastbound Study Section into Analysis Segments – Use same segments as for Example Problem 1.
4. Assemble Data – The same demand data is used as in Example Problem #1, however; the geometric cross section data is changed to reflect the new proposed cross section.
5. Compute Auto LOS – The required inputs and computation results are shown in Exhibit 26: Example 2 - Computation of Auto LOS.

a. Compute Demand – Same as Problem 1.
b. Compute Capacity –The adjusted saturation flow rate (vehicles per lane per hour of green) are computed using the procedures given in Chapter 16, Signalized Intersections, of the Highway Capacity Manual (2000), but this time with no left turn adjustment, because left turns can now be made in the left turn lane. The number of through lanes is reduced to 1 lane. The v/c check identifies one segment that will be over capacity.
c. Compute Mean Through Speed – Same procedure with different input data as in Problem #1.
d. Compute Stops and Left Lanes – Same procedure with different input data as in Problem #1.
e. Compute Auto LOS – Same procedure with different input data as in Problem #1. The overall facility LOS is “F” because one of the segments had a v/c ratio greater than 1. This overrides the normal averaging of segment LOS (which would have resulted in an average LOS D).

6. Compute Pedestrian LOS – The computations are shown in Exhibit 27: Example 2 - Computation of Pedestrian LOS.
   a. Compute Pedestrian Density LOS – Same procedure with different input data as in Problem #1.
   b. Compute Pedestrian Segment LOS – Same procedure with different input data as in Problem #1.
   c. Compute Pedestrian Intersection LOS – Same procedure with different input data as in Problem #1.
   d. Compute Roadway Crossing Difficulty Factor (RCDF) – Same procedure with different input data as in Problem #1. Note that pedestrian crossing distance is only to the median, because the two-way-left-turn is considered (in this example jurisdiction) to function as a de-facto median in this case. Other jurisdictions may consider the two-way-left-turn-lane to not provide a refuge for crossing pedestrians, in which case the full curb-to-curb street width would be used to compute the RCDF.
   e. Compute Pedestrian Facility LOS – Same procedure with different input data as in Problem #1.
7. Compute Transit LOS – The data and computation steps are shown in Exhibit 28: Example 2 - Computation of Transit LOS.
   a. Input Data – Same input data as in Problem #1.
   b. Compute Mean Bus Speed – Same procedure as in Problem #1 with different input data (auto speed from the auto LOS computation).
   c. Compute Perceived Travel Time Rates – Same procedure as in Problem #1 with different input data (bus speed and pedestrian LOS).
   d. Compute Transit LOS – Same procedure as in Problem #1 with different input data.
8. Compute Bicycle LOS – The data and computation steps are shown in Exhibit 29: Example 2 - Computation of Bicycle LOS.
   a. Geometric Input Data – Same data as in Problem #1, except for the road is now considered “divided”.
   b. Performance and Other Input Data – Same procedure as in Problem #1 with different input data (auto speed from auto LOS computation).
   c. Compute Bicycle LOS – Same procedure as in Problem #1 with different input data.
9. Summary Table of LOS Results – The summary table of modal LOS results is given in Exhibit 30. Example Problem 2 Results Summary

10. The above analysis is then repeated for the reverse direction of travel on the street.

- Conclusions: The results are summarized in Converting 4 traffic lanes into 2 bike lanes, 2 traffic lanes, and a two-way-left-turn-lane (TWLTL) (and adding a pedestrian buffer zone between the sidewalk and the curb) caused auto LOS to deteriorate on two of the five segments, but overall facility LOS for auto remained unchanged by the conversion.
- The conversion improved bicycle LOS on one of the five segments but did not significantly affect overall facility LOS for bicycles. This is because the benefits of adding a bike lane and prohibiting parking were partially balanced out by the increase in vehicle traffic in the right lane adjacent to the bicycle lane.
- The conversion worsened transit LOS for two of the five segments, but had no significant impact on overall transit LOS.
- The conversion significantly improved pedestrian LOS. The addition of a landscaped buffer strip with trees more than made up for the loss of on-street parking (from the point of view of pedestrians walking on the street).

Exhibit 25: Impacts of Lane Conversion. The key conclusions are highlighted below.

- Converting 4 traffic lanes into 2 bike lanes, 2 traffic lanes, and a two-way-left-turn-lane (TWLTL) (and adding a pedestrian buffer zone between the sidewalk and the curb) caused auto LOS to deteriorate on two of the five segments, but overall facility LOS for auto remained unchanged by the conversion.
- The conversion improved bicycle LOS on one of the five segments but did not significantly affect overall facility LOS for bicycles. This is because the benefits of adding a bike lane and prohibiting parking were partially balanced out by the increase in vehicle traffic in the right lane adjacent to the bicycle lane.
- The conversion worsened transit LOS for two of the five segments, but had no significant impact on overall transit LOS.
- The conversion significantly improved pedestrian LOS. The addition of a landscaped buffer strip with trees more than made up for the loss of on-street parking (from the point of view of pedestrians walking on the street).

Exhibit 25: Impacts of Lane Conversion

	Auto LOS		Transit LOS		Bicycle LOS		Pedestrian LOS	
Segment	Before	After	Before	After	Before	After	Before	After
1	C	C	B	C	E	D	E	E
2	C	D	B	C	E	E	E	D
3	C	C	A	A	E	E	E	C
4	C	C	B	B	E	E	E	E
5	B	C	C	C	E	E	E	D
Facility	C	C	B	B	E	E	E	D

Exhibit 26: Example 2 - Computation of Auto LOS

1. Compute Eastbound Hourly Demand (v)

Segment	Weekday ADT (vpd)	Peak Factor k (#)	Dir. Factr d (#)	Pk.Hr.Fac PHF (#)	Demand v (vph)
1	10,000	0.080	0.55	0.92	478
2	15,000	0.080	0.55	0.92	717
3	10,000	0.080	0.55	0.92	478
4	15,000	0.080	0.55	0.92	717
5	10,000	0.080	0.55	0.92	478

2. Compute Eastbound Hourly Capacity and V/C

Segment	Adjusted Saturation (vphgl)	Thru Lanes One-Dir. (#)	Thru (g/C) (#)	Capacity (vph)	v/c	v/c Check
1	1550	1	0.50	775	0.62	OK
2	1550	1	0.50	775	0.93	OK
3	1700	1	0.45	765	0.63	OK
4	1700	1	0.45	765	0.94	OK
5	1700	1	0.44	748	0.64	OK

Adjusted Sat. Flows computed per Chapter 16, Signalized Intersections.

3. Compute Mean Through Speed

Segment	Free Speed (mph)	Segment Length (ft)	Cycle Length (sec)	Progress. Quality (#)	Intersect Delay (sec)	Average Speed (mph)
1	35	600	60	5	6.4	22.6
2	35	600	60	5	11.8	17.4
3	35	1200	90	3	21.8	18.1
4	35	1200	120	3	39.2	13.1
5	35	1680	120	3	29.3	18.5
Total/Ave.		5280				17.0

4. Compute Stops & % Left Lane

Segment	Progress. Quality (#)	Stops Per Veh. (stps/veh)	Segment Length (ft)	Stops Per Mile (stps/mi)	Left Trn Ln (Yes=1) (0,1)
1	5	0.48	600	4.23	1
2	5	0.90	600	7.94	1
3	3	0.72	1200	3.16	1
4	3	1.26	1200	5.53	1
5	3	0.73	1680	2.28	1
Total/Ave		4.08	5280	4.08	1.00

5. Compute Auto LOS

Segment	LOS A (%)	LOS B (%)	LOS C (%)	LOS D (%)	LOS E (%)	LOS F (%)	Weight. Ave.	Auto LOS
1	13.2%	34.3%	25.9%	21.7%	7.7%	4.4%	3.11	C
2	5.6%	20.5%	25.8%	30.6%	15.6%	10.5%	3.87	D
3	16.6%	37.6%	24.1%	18.5%	6.1%	3.4%	2.89	C
4	9.8%	29.5%	27.1%	25.5%	10.1%	6.0%	3.39	C
5	19.9%	39.8%	22.2%	20.9%	5.1%	2.7%	2.91	C
Average	13.6%	34.8%	25.7%	14.2%	7.5%	4.3%	2.80	C
weights:	1	2	3	4	5	6		

Exhibit 27: Example 2 - Computation of Pedestrian LOS

1. Compute Pedestrian Density LOS

Seg.	Sidewalk Width (ft)	Ped. Flow (pph)	Ped. Density LOS #	Ped. Density LOS
1	5	4000	4.12	D
2	5	1500	1.84	B
3	5	1000	1.27	A
4	5	500	0.65	A
5	5	50	0.07	A

Density LOS Lookup	
Ped/hr/ft	LOS
0	A
300	B
420	C
600	D
900	E
1380	F

2. Compute Pedestrian Segment LOS

Seg.	Outside Lane (ft)	Bike/Shouldr Lane Width (ft)	On-Street Parking (%)	Barrier (Y/N)	Buffer Width (ft)	Dir. Traf Volume (vph)	Lanes One-Dir (lanes)	Midblock Traf Spd (mph)	Ped. Seg. LOS
1	12	5	0%	Yes	8	478	1	28.8	2.20
2	12	5	0%	Yes	8	717	1	26.2	2.77
3	12	5	0%	Yes	8	478	1	26.5	2.15
4	12	5	0%	Yes	8	717	1	24.0	2.72
5	12	5	0%	Yes	8	478	1	26.7	2.16

Note that Midblock traffic speed is average of: auto free-flow speed and mean auto speed with int. delay.

3. Compute Pedestrian Intersection LOS

Seg.	RTOR+ Perm LT (vph)	X-Street Volume (vph)	X-Street PHF (#)	X-Street Speed (mph)	X-Street Lanes (#)	Ped Delay (sec)	Right Trn Channel Islands (#)	Ped. Intersect LOS #
1	50	500	0.92	25	2	7.5	0	2.48
2	75	500	0.92	25	2	7.5	0	2.52
3	50	750	0.92	35	4	13.6	0	3.03
4	50	1200	0.92	40	4	18.2	2	4.12
5	50	1500	0.92	45	6	18.8	2	4.85

Pedestrian Delay computed per Chapter 18 method.

4. Compute Roadway Crossing Difficulty Factor (RCDF)

Seg.	Signal Spacing (ft)	Signal Cycle (sec)	Cross St. g/C (#)	Divert Delay (sec)	Crossing Distance (ft)	Vehicle Speed (mph)	Vehicle Vol 2-Dir (vph)	Ave. Wait (sec)
1	600	60	0.17	135	20	28.8	800	15
2	600	60	0.17	135	20	26.2	1,200	35
3	1200	90	0.11	264	20	26.5	800	15
4	1200	120	0.08	279	20	24.0	1,200	35
5	1680	120	0.08	370	20	26.7	800	15

5. Compute Pedestrian Facility LOS

Seg.	Min. Wait,Divrt (sec)	Crossing LOS (#)	No Cross LOS (#)	RCDF (#)	Ped. NDLOS (#)	Ped. Density LOS #	Ped. Fac. LOS (#)	Ped. Facility LOS
1	15	2.00	2.85	0.89	2.53	4.12	4.12	E
2	35	4.00	3.04	1.13	3.43	1.84	3.43	D
3	15	2.00	2.96	0.87	2.58	1.27	2.58	C
4	35	4.00	3.38	1.08	3.66	0.65	3.66	E
5	15	2.00	3.36	0.82	2.75	0.07	2.75	D
Ave							3.15	D

Exhibit 28: Example 2 - Computation of Transit LOS

1. Input Data

Segment	Transit Frequency (bus/h)	On-Time Perform. (%)	Stops with Shelter (%)	Stops with Bench (%)	Load Factor (p/seat)	. CBD (Y/N)
1	18	48%	100%	100%	1.1	Yes
2	18	48%	100%	100%	1.2	Yes
3	9	50%	0%	100%	0.8	No
4	4	65%	0%	0%	0.7	No
5	2	70%	0%	0%	0.5	No

2. Compute Mean Bus Speed

Segment	Length (ft)	Auto Spd (mph)	Bus Stops (#)	Delay/Stop (sec)	Ave Bus (mph)
1	600	22.6	1	20	10.7
2	600	17.4	1	20	9.4
3	1200	18.1	1	15	13.6
4	1200	13.1	1	15	10.6
5	1680	18.5	1	10	15.9
Total/Ave	5280	17.0			12.4

Average Bus Speed computed per Chapter 24 method.

3. Compute Transit Perceived Travel Time and Headway Factors

Segment	a1 factor	IVTTR min/mi	EWTTR min/mi	ATR min/mi	PTTR	Fptt	Fh
1	1.41	5.59	1.83	0.41	11.12	0.68	3.75
2	1.60	6.38	1.83	0.41	13.43	0.64	3.75
3	1.00	4.42	1.69	0.05	7.74	0.90	3.46
4	1.00	5.69	0.83	0.00	7.34	0.92	2.83
5	1.00	3.77	0.61	0.00	4.99	1.08	1.97

IVTTR = In-Vehicle Travel Time Rate
EWTTR = Equivalent Wait Travel Time Rate
ATR = Amenity Time Rate
PTTR = Perceived Travel Time Rate
Fptt = Perceived Travel Time Factor
Fh = Headway Factor

4. Compute Transit LOS

Segment	Wait/Ride Score	Ped LOS	LOS Score	Transit LOS
1	2.56	4.12	2.78	C
2	2.42	3.43	2.89	C
3	3.13	2.58	1.70	A
4	2.61	3.66	2.63	B
5	2.12	2.75	3.23	C
Average			2.65	B

Exhibit 29: Example 2 - Computation of Bicycle LOS

1. Geometric Input Data

Segment	Outside Lane Width (ft)	Bike/Shldr Lane Width (ft)	Through Lanes (lanes)	Divided/ Undivided (D/UD)	Sig. Int Cross-Dist (ft)	Unsig.Conf Per Mile (conf/mi)
1	12	5	1	D	40	0.0
2	12	5	1	D	40	10.0
3	12	5	1	D	64	5.0
4	12	5	1	D	64	2.0
5	12	5	1	D	88	1.0

2. Performance and Other Input Data

Segment	Traffic Volume (vph)	Heavy Vehicle (%)	Midblock Traffic Spd (mph)	On-Street Parking (%)	Pavement Rating (#)
1	478	3%	28.8	0%	4.0
2	717	6%	26.2	0%	4.0
3	478	12%	26.5	0%	3.5
4	717	12%	24.0	0%	4.0
5	478	6%	26.7	0%	4.0

Pavement Rating: 1=Poor, 5=Excellent
Midblock traffic speed = average of: auto free-flow speed, and mean auto speed with intersection delay.

3. Compute Bicycle LOS

Segment	Prelim. Eff. Width (Wv)	Effective Width (We)	Speed Factor (#)	Segment LOS (#)	Intersect LOS (#)	Bicycle Score (#)	Bicycle LOS
1	17.0	22.0	3.25	2.38	2.00	3.31	D
2	17.0	22.0	2.86	2.98	2.45	3.80	E
3	17.0	22.0	2.91	4.33	2.37	3.84	E
4	17.0	22.0	2.37	3.86	2.82	3.72	E
5	17.0	22.0	2.95	2.82	2.73	3.51	E
Average						3.64	E

Exhibit 30. Example Problem 2 Results Summary

Direction =Eastbound

Segment	Auto LOS	Transit LOS	Bicycle LOS	Pedestrian LOS
1	C	C	D	E
2	D	C	E	D
3	C	A	E	C
4	C	B	E	E
5	C	C	E	D
Facility	C	B	E	D

VIII. REFERENCES

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