Final Report

NCDOT Level of Service Software Program for Highway Capacity Manual Planning Applications

Research Conducted for

The North Carolina Department of Transportation

By:

Shannon J. Fain, P.E.,
Chris M. Cunningham, P.E.,
Robert S. Foyle, P.E., and
Nagui M. Rouphail, Ph.D.

At the:

Institute for Transportation Research and Education
North Carolina State University
Raleigh, NC

August 2006

Technical Report Documentation Page

1. Report No. **FHWA/NC/2006-06**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle **NCDOT Level of Service Software Program for Highway Capacity Manual Planning Applications**		5. Report Date **August 2006** 6. Performing Organization Code
7. Author(s) **Shannon J. Fain, Chris M. Cunningham, Robert S. Foyle, Nagui M. Rouphail**		8. Performing Organization Report No.
9. Performing Organization Name and Address **Institute for Transportation Research and Education North Carolina State University Campus Box 8601, Raleigh, NC 27695**		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address **North Carolina Department of Transportation Reserch and Analysis Group 1 South Wilimington Street Raleigh, NC 27601**		13. Type of Report and Period Covered **Final Report July 2002 – June 2005** 14. Sponsoring Agency Code **2003-12**
15. Supplementary Notes NCDOT Research Engineer: **Mr. Richard J. Lakata, P.E.**		

16. Abstract

The Transportation Planning Branch (TPB) of the North Carolina Department of Transportation (NCDOT) desired a user-friendly tool for determining highway capacity and service volumes for freeways, multilane highways, arterials, and two-lane highways based upon the specific conditions present in North Carolina for use in planning applications. The tool developed in this project is based upon the methodology and theory presented in the 2000 Highway Capacity Manual, with default values established specifically for North Carolina conditions across the three regions of the state. The tool includes a unique graphical interface and plot of the measure of effectiveness against average annual daily traffic. This tool allows for various planning scenarios to be examined in an efficient, yet accurate manner, both visually and numerically.

Additionally, a comprehensive sensitivity analysis on the input parameters was carried out. The analysis showed that four (4) inputs had high sensitivity, eleven (11) inputs had medium sensitivity, and six (6) inputs had low sensitivity. NCDOT's future data collection efforts can be expanded and targeted to include information on the most sensitive inputs to enhance future planning analysis efforts by establishing documented default values on these inputs.

17. Key Words **Freeway, multilane, two-lane, arterial, planning, software, level-of-service, service volumes**	18. Distribution Statement

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages **141**	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

DISCLAIMER

The contents of this report reflect the views of the author(s) and not necessarily the views of North Carolina State University. The author(s) are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either the North Carolina Department of Transportation or the Federal Highway Administration at the time of publication. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGMENTS

The research team wishes to thank the North Carolina Department of Transportation and the Federal Highway Administration for initiating and funding this project. Richard J. Lakata, P.E., the NCDOT Research Engineer assigned to monitor this project, deserves special thanks for providing tremendous support for this project in organizing and leading project team meetings, taking and distributing minutes of meetings, and processing contract documents. In addition, the research team thanks the members of the Steering and Implementation Committee in guiding the team on this project through numerous project meetings. Members of the committee included David Wasserman, P.E. (chair), Mike Bruff, P.E., Rhett Fussell, P.E., Ed Johnson, P.E. (CAMPO), Felix Nwoko (DCHC MPO), Tim Padgett, P.E., Joe Stevens, and Scott Walston, P.E. The team also thanks all the other NCDOT employees in the Transportation Planning Branch who contributed their time providing input and comments on the software product for this project, especially Terry Arellano, P.E., and Majed Al-Ghandour, P.E. Special thanks go to Kent Taylor for input and guidance on analyzing traffic count information for use in determining default factors for the software program.

The research team expresses gratitude to Joseph S. Milazzo, II, P.E., former Program Manager at ITRE, for starting this project. Jonathan Lewis, a student at N.C. State University, programmed the entire software program, and did an outstanding job solving many technical issues. Jeff Robinette, undergraduate student at N.C. State University, provided support on the literature search and the sensitivity analysis.

Without the help of all the above individuals, this project could not have been successfully accomplished in the manner it was.

EXECUTIVE SUMMARY

The Transportation Planning Branch (TPB) of the North Carolina Department of Transportation (NCDOT) desired a user-friendly tool for determining highway capacity for various facilities based upon the specific conditions present in North Carolina for use in planning applications. The tool was to be based upon the methodology and theory already present in the 2000 Highway Capacity Manual (HCM), but it would be geared specifically to North Carolina. The tool would include a graphical interface that would allow for various planning scenarios to be examined in an efficient, yet accurate manner.

The software program developed in this project allows the user to examine one of four primary facility types: freeways, multilane highways, arterials, and two-lane highways. The tool includes various conditions, such as the region of the state in which the facility is located (Coastal, Piedmont, and Mountains) and the environment surrounding the facility (urban, rural, suburban etc.), among others, as user inputs. Default values are provided for each of the facility types that are specific to that particular region and environment and that are based upon collected data and the guidance and experience of the TPB staff. In particular, detailed vehicle classification data provided for the project by the Traffic Surveys Unit of NCDOT allowed for specific default truck percentages to be developed for the various regions and environments present throughout the state. Users are able to employ the assigned default values for their analysis, or change the values in lieu of more specific or current information for their particular project, in calculating service volumes and capacity for the highway being examined.

Furthermore, to determine which characteristics resulted in a high degree of change in highway capacity, a thorough sensitivity analysis was carried out on all of the inputs required by the 2000 HCM methodology for each highway type addressed in the study. From this analysis of 21 inputs, four (4) inputs had high sensitivity, eleven (11) inputs had medium sensitivity, and six (6) inputs had low sensitivity. For inputs where existing data is not being collected, future collection efforts can be designed to comprehensively address establishing better default values for those specific inputs. Additionally, the results of the analysis can be exported to TransCAD® in a manner that facilitates easy use by the TPB staff for future projects located throughout the state.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Transportation Planning Branch is responsible for working with outside planning agencies in providing engineering and planning assistance for the current, proposed, and potential highway network in North Carolina. This branch is charged with identifying future highway needs through the transportation planning process. This process requires the use of modeling and forecasting techniques to determine potential needs and opportunities in the transportation system. Accurate travel demand modeling requires appropriate values for roadway capacities and service volumes at various levels of service (LOS).

Tools such as the 2000 Highway Capacity Manual (HCM) are very valuable for performing detailed analyses of facilities and corridors given a series of input data. However, the paucity of information typically available at the planning stages coupled with the relative complexity of the HCM product make direct use of the HCM impractical or inefficient for forecasting applications. The HCM is primarily designed for operational analyses; it is not particularly well suited to the reverse process of determining acceptable roadway demands for various maximum service volumes or capacities at LOS thresholds.

The Transportation Planning Branch does not currently possess a consistent method for determining expected service volumes and capacities for a given set of roadway, geographic, traffic, or other characteristics. Current methods use only a few variables and are not consistent across the State. The Florida Department of Transportation (FDOT) has developed a means to anticipate these critical planning values. The FDOT computer software provides users with LOS standards and methodologies. This project proposes to develop a similar user-friendly computer program that will provide users with accurate, consistent expected hourly service volumes and expected daily traffic for various facilities, tailored to North Carolina conditions. The product will allow for appropriate variation among geographic, terrain, traffic, and other differences that may affect facility performance apart from roadway characteristics.

RESULTS OF LITERATURE REVIEW

2000 Highway Capacity Manual Review

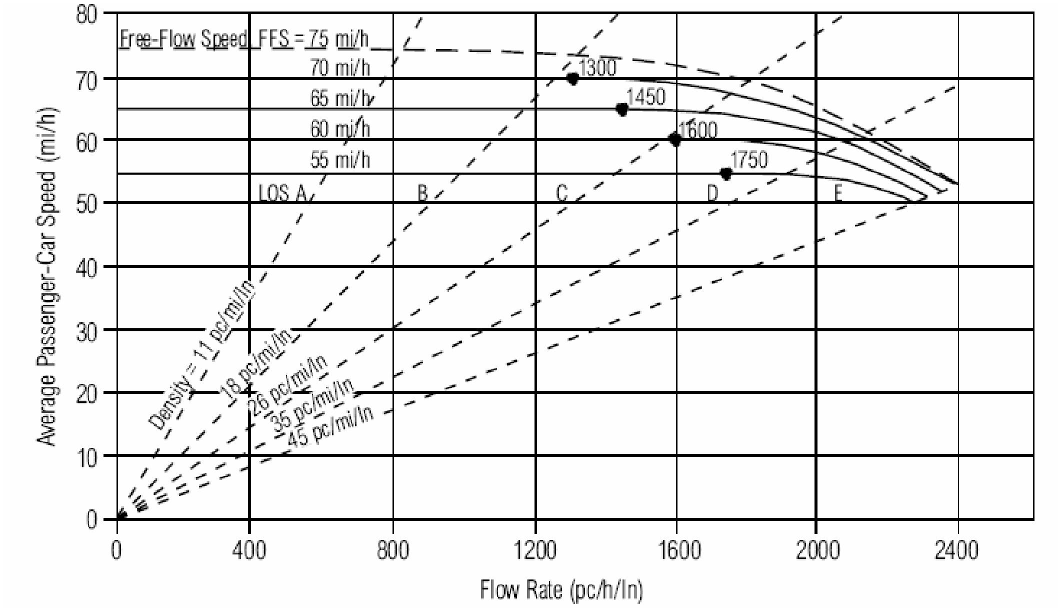
The 2000 Highway Capacity Manual provides methodologies for estimating the level of service and capacity for both uninterrupted and interrupted transportation facilities. For each facility there are one or more performance measures, or measures of effectiveness (MOEs), which characterize the user's perception of the operating conditions of that facility. It is critical to understand at the outset that *users, not facilities,* experience the travel characterized by LOS in the 2000 HCM. By implication, there are different levels of service for each user, and indeed even within a travel mode there are different service qualities possible by approach or direction, as well as by time of day. *For simplicity, this study focuses solely on LOS from the perspective of drivers of motor vehicles.* However, regardless of user mode, approach, or direction, each LOS represents a range of values for that facility's MOE. This range varies by a lettering system 'A' through 'F'. LOS 'A' represents a user perception of the MOE as being excellent, with 'F' denoting a breakdown in the facility.

The four facilities of interest for this project are freeways, multilane highways, two-lane highways and urban streets (also known as arterials). A brief description of each of these facility's MOE and LOS follows. A detailed summary of the HCM procedures for determining the LOS of each facility type can be found in Appendix A.

Freeways

A freeway is an uninterrupted flow facility comprised of two or more lanes per direction with complete access control and no signals or at-grade intersections involving mainline (through) traffic. A basic freeway segment is not influenced by ramp or weaving segments and operates under uniform conditions. Pedestrians and bicycles are not permitted to travel on freeways in North Carolina.

The measure of effectiveness for a basic freeway segment is density, in units of passenger-cars per mile per lane (pc/mi/ln). It is a function of flow rate and average passenger-car speed. This is shown as a graphical representation in the HCM in Exhibit 23-3, which is seen below in Figure 1. The various LOS can be seen as breaking points, or thresholds, on the basis of density boundary values.



Note:
Capacity varies by free-flow speed. Capacity is 2400, 2350, 2300, and 2250 pc/h/ln at free-flow speeds of 70 and greater, 65, 60, and 55 mi/h, respectively.

Figure 1. Speed Flow Curves and LOS for Basic Freeway Segments (HCM Exhibit 23-2)

The specific LOS thresholds for a freeway facility are shown below in Table 1.

LOS	Density Range (pc/mi/ln)
A	0 – 11
B	> 11 – 18
C	> 18 – 26
D	> 26 – 35
E	> 35 – 45
F	> 45

Table 1. LOS Thresholds for a Freeway Facility

Density is the preferred MOE because it is easily measured in the field and is more sensitive to the level of comfort and convenience that freeway users are experiencing than is speed or travel time. In fact, as volumes increase, LOS can decrease dramatically on a freeway with speed remaining constant or decreasing minimally. Additionally, because thresholds have been established, it is important to note that actual densities vary throughout each LOS range. Therefore, when calculating a specific freeway density, the analyst should recognize that a density of 26 pc/mi/ln (LOS C) and 27 pc/mi/ln (LOS D) are really not that different even though the designated letter indicates to most analysts a large difference. This is true for all four facility types. For further explanation of the methodology and calculations for obtaining the LOS for the freeway facility, see Appendix A.

Multilane Highways

A multilane highway consists of four to six lanes with or without a median or two-way left-turn lane (TWLTL). These highways differ from freeways mainly based on access control and signalized intersections. Where freeways allow access only at grade-separated interchanges, multilane highways allow access at driveways and at-grade intersections, some of which are signalized. In the HCM, signalized intersections are spaced no closer than two miles apart on facilities considered to be multilane highways. Routes with signalized intersection spacing closer than one every two miles are treated in the urban streets chapter.

The MOE for a multilane highway is the same as that of a freeway facility, which is density in passenger-cars per mile per lane (pc/mi/ln). In fact, although there are differences in allowable access and the use of signalized intersections, the LOS of the facility is calculated in a similar fashion. Of course, the discrepancies in these two facilities cause a decrease in the capacity of a multilane highway verses a freeway. As with freeways, a graphical representation is a common way of depicting LOS thresholds. This is shown below in Figure 2.

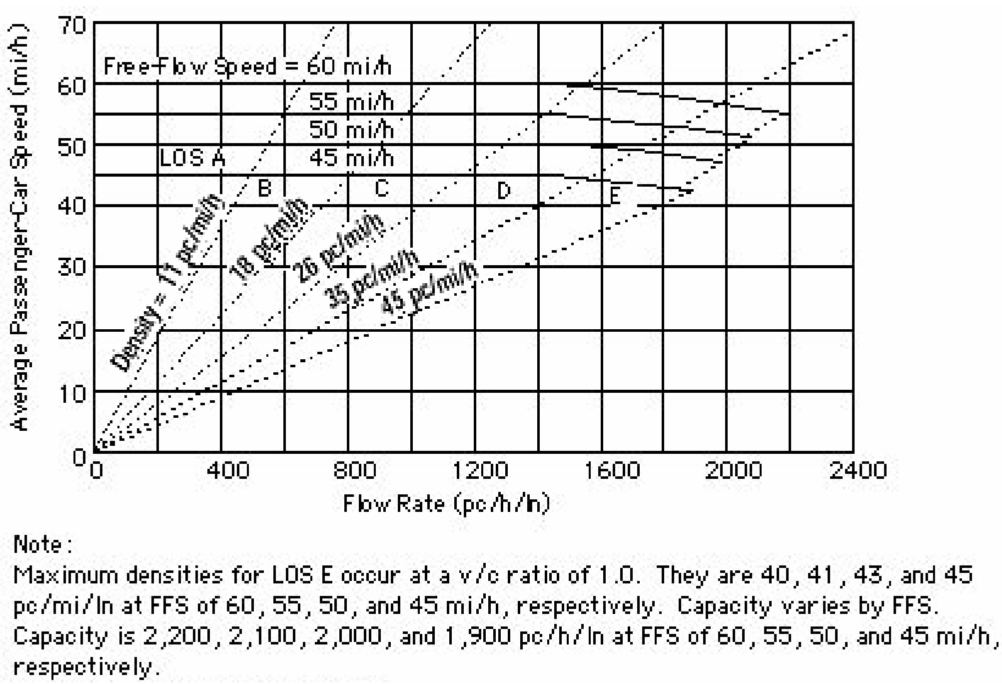


Figure 2. Speed Flow Curves and LOS for Multilane Highways (HCM Exhibit 21-3)

The LOS thresholds are denoted below in Table 2.

LOS	Density Range (pc/mi/ln)
A	0 – 11
B	> 11 – 18
C	> 18 – 26
D	> 26 – 35
E	> 35 – varying
F	Varies (see Fig. 2, note above)

Table 2. LOS Thresholds for a Multilane Facility

It is noted in the HCM that the maximum threshold for LOS E is very hard to determine because of "highly unstable and variable traffic flow." Therefore, the thresholds for density at the maximum value for LOS E and F should be referred to in the note above under Figure 2. For further explanation of the methodology and calculations for obtaining the LOS for the multilane facility, see Appendix A.

Urban Streets (Arterials)

Urban streets differ from the previously mentioned facilities in that those facility types are generally considered to have "uninterrupted" flow (for mainline through movements). Urban streets, or "signalized arterials" as they are often called, typically have increased roadside development, increased density of access points, and spacing of signalized intersections less than two miles apart. Average travel speed is the MOE used for determining LOS on urban streets. Speed on an urban street is affected by the street environment, interactions between vehicles, and traffic control.

Each direction of travel is analyzed separately and the methodology does not measure access but rather *mobility*. The methodology does not account for on-street parking, access control, grades or capacity constraints between intersections, medians or two-way left turn lanes, queues backing up into previous intersections, or cross-street congestion blocking through traffic.

LOS is determined using Table 3 once the urban street class, range of FFS, typical FFS, and average travel speed are known.

Urban Street Class	I	II	III	IV
Range of free-flow speeds (FFS)	45 – 55 mi/h	35 – 45 mi/h	30 – 35 mi/h	25 – 35 mi/h
Typical FFS	50 mi/h	40 mi/h	35 mi/h	30 mi/h
LOS	Average Travel Speed (mi/h)			
A	> 42	> 35	> 30	> 25
B	> 34 – 42	> 28 – 35	> 24 – 30	> 19 – 25
C	> 27 – 34	> 22 – 28	> 18 – 24	> 13 – 19
D	> 21 – 27	> 17 – 22	> 14 – 18	> 9 – 13
E	> 16 – 21	> 13 – 17	> 10 – 14	> 7 – 9
F	≤ 16	≤ 13	≤ 10	≤ 7

Table 3. Urban Street LOS by Class (HCM Exhibit 15-2)

For further explanation of the methodology and calculations for obtaining the LOS for the urban street (arterial) facility, see Appendix A.

Two-Lane Highways

A two-lane highway is an undivided facility with one lane in each direction of travel. Unlike multilane highways and freeways, flow in each direction of a two-lane highway influences flow in the opposing direction. The two service measures for two-lane highways are percent time-spent-following and average travel speed. Percent time-spent-following is the average percentage of travel time that a vehicle spends behind a slower vehicle waiting to pass and represents freedom to maneuver, comfort and convenience. Since this MOE cannot be easily measured in the field, its surrogate is the percentage of vehicles traveling with less than 3-second headways. Average travel speed is the length of a segment divided by the average travel time of all vehicles in both directions during a given time interval. This MOE reflects mobility.

There are two classifications of two-lane highways based on the perceived purpose of the facility by the highway user. Class I consists of those facilities where *mobility* is the primary function. On these highways LOS is defined in terms of both average travel speed and percent time-spent-following. Class II is comprised of highways for which *accessibility* is more important than mobility. For these highways, only percent time-spent-following is considered when determining LOS. Additionally, users of Class II highways tolerate a higher percent time-spent-following since these facilities tend to service shorter trips and different purposes than Class I highways.

Tables 4 and 5 give LOS criteria and thresholds for two-lane highways in Class I and II, respectively. Because a graphical representation is frequently used, Figure 3 is included below Table 4 and shows LOS criteria for Class I facilities graphically. Note that *both* MOE criteria must be satisfied to achieve a particular LOS.

LOS	Percent Time-Spent-Following	Average Travel Speed (mi/h)
A	0 – 35	> 55
B	> 35 - 50	> 50 - 55
C	> 50 - 65	> 45 - 50
D	> 65 - 80	> 40 - 45
E	> 80	≤ 40
F	Applies whenever the flow rate exceeds the segment capacity	

Table 4. LOS Criteria for Two-Lane Highways in Class I (HCM Exhibit 20-2)

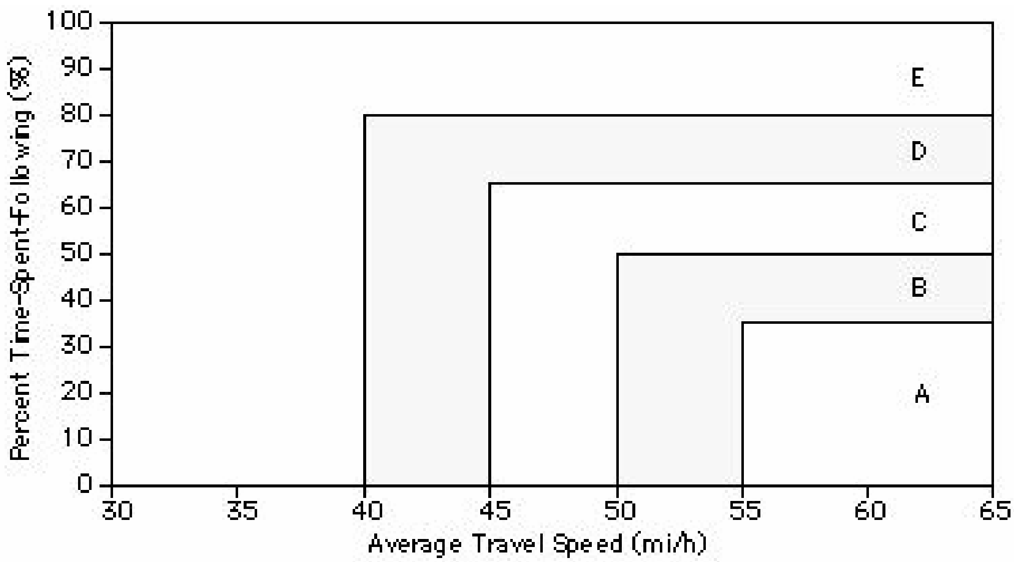


Figure 3. LOS Criteria for Two-Lane Highways in Class I (HCM Exhibit 20-3)

LOS	Percent Time-Spent Following
A	≤ 40
B	> 40 – 55
C	> 55 – 70
D	> 70 – 85
E	> 85
F	Applies whenever the flow rate exceeds the segment capacity

Table 5. LOS Criteria for Two-Lane Highways in Class II (HCM Exhibit 20-4)

For further explanation of the methodology and calculations for obtaining the LOS for two-lane highways, see Appendix A.

Current Practices

The four facilities discussed in our review of the 2000 HCM each have particular different unknown factors. Note that most analyses in the HCM typically use the peak 15-min. flow rate converted to an hourly flow rate in the analysis. Because there is no standard method for determining LOS based on predicted AADT and several unknowns in North Carolina, a review was conducted on NCDOT's current practices for predicting LOS. Each method used was based on the 2000 HCM; however, as will be seen, there was no unified standard means of using the HCM.

NCDOT Transportation Planning Branch and Asheville, North Carolina

Presently, the Transportation Planning Branch of NCDOT is responsible for "identifying long range transportation needs through the transportation planning process" *(NCDOT Purpose and Needs Guidelines, 8/29/00)*. The transportation planning process sometimes reveals that new roads must be built or old roads altered to relieve congestion and/or increase capacity. The ultimate result of this process is to secure all permits and let the project construction. The Transportation Planning Branch initiates this process by developing what is known as a "Purpose and Needs" statement, which outlines the following:

- why the proposed action needs to be taken
- how much the action will cost
- how the action will impact the environment
- why alternatives are not practicable
- what problems will arise if the action is not taken

One important aspect of the Purpose and Needs statement for any project is the comparison between the existing roadway conditions and the projected roadway conditions which would exist if the action were taken. When making this comparison, engineers must present data depicting the current and projected AADT, peak hour characteristics, truck percentages, capacity, volume to capacity ratios, and LOS of the road.

Generation of this data for the projected roadway is currently developed in many different ways around the state because there is not one standard method accepted and employed by NCDOT. For instance, NCDOT developed a set of tables, charts, and practices specifically for dealing with capacity and level of service for the town of Asheville. The Asheville model is based upon the concept of ultimate capacity, which refers to the number of vehicles per hour that can be serviced by a roadway at the boundary between LOS E and LOS F. The Asheville model uses this as the maximum acceptable number of vehicles that a roadway should support, rather than using the more traditional concept of target volume as the boundary between LOS C and LOS D, or some other approved design threshold.

This model also utilizes a corridor and area-wide analysis method based on the procedures presented in Chapter 30 of the HCM. The area-wide analysis chapter of the HCM is designed to provide a less iterative, more simplistic approach to estimating speed, delay, travel time, and other performance measures for large-scale analysis. The methodologies in Chapter 30 are derived from the more complex procedures in previous HCM chapters. These area-wide methodologies are only valid when applied to a large number of facilities and are not designed to provide results as accurate and reliable as those for a single point, segment, or facility given in earlier HCM chapters. There are procedures in Chapter 30 for highway and transit systems but not for pedestrian or bicycle facilities. The highway procedures are designed for use with freeway, arterial, and rural highway systems.

The methodology for all highway facilities involves five steps. The first of these steps is to input all facility data, divide the area into the appropriate links and nodes, and identify the facility type of each link. Facility data may include daily traffic, peak-hour volume, turning movements, facility type, speed limit, signal data, number of lanes, percent trucks, and terrain. Links are defined as segments where demand and capacity do not vary by more than ten percent and do not contain a major intersection or a merge or diverge point. Table 6 can be of assistance in assigning facility type to each link.

Functional Class	Subsystem	Facility Type
Freeway	Freeway	Basic
On-ramp	Arterial	Class III[c]
Off-ramp	Arterial	Class III
Expressway[a]	Arterial	Class I
Divided arterial[a]	Arterial	Class I, II, III
Undivided arterial[a]	Arterial	Class II, III
Collector[a]	Arterial	Class III
Local[a]	Arterial	Class IV
Centroid connector	None[b]	None[b]

Notes:

a. Analyze as rural highway subsystem (multilane or two-lane facility, as appropriate) if there are no signals or signal are spaced more than 3 km apart.
b. Centroid connectors typically have near-infinite capacity and a fixed travel speed. They do not fit any HCM facility type.
c. Treat on-ramp as arterial with 100-percent green time.

Table 6. Example Functional Class-Facility Type Correlation (HCM Exhibit 30-1)

The second and third steps are to determine the FFS and capacity of each link. Since an area-wide analysis involves too many segments to feasibly measure FFS in the field, the procedures used for each specific facility type in Part III of the HCM should be used. The procedures for capacity found in these sections should also be used; however, the capacities in passenger cars per hour must be converted to vehicles per hour for the purpose of queue and delay calculations. HCM equations 30-1, 30-2, and 30-3 below can be used to calculate the mixed-vehicle capacity of a freeway link, a rural highway link, and an arterial link, respectively. Default tables specific to a given region may be developed to simplify the process of determining FFS and capacity for each link.

$$c = Q * N * f_{HV} * f_p * PHF \qquad (30\text{-}1)$$

where

- c = capacity (veh/h),
- Q = PCE capacity from HCM Chapter 23 (pc/h/ln),
- N = number of through lanes (ignoring auxiliary and exit-only lanes),
- f_{HV} = heavy-vehicle adjustment factor,
- f_p = driver population adjustment factor, and
- PHF = peak-hour factor.

$$c = Q * f_{HV} \qquad (30\text{-}2)$$

where

- c = capacity (veh/h),
- Q = 1700 (pc/h/ln), and
- f_{HV} = heavy-vehicle adjustment factor.

$$c = s_o * N * f_w * f_{HV} * f_g * f_p * f_{bb} * f_a * f_{LU} * f_{LT} * f_{RT} * f_{Lpb} * f_{Rpb} * PHF * g/C \qquad (30\text{-}3)$$

where

- c = capacity (veh/hr)
- PHF = peak hour factor
- g/C = effective green time per cycle
- s_o = base saturation flow rate per lane (pc/h/ln)
- N = number of lanes in lane group
- f_w = adjustment factor for lane width
- f_{HV} = adjustment factor for heavy vehicles in traffic stream
- f_g = adjustment factor for approach grade
- f_p = adjustment factor for existence of a parking land and parking activity adjacent to lane group
- f_{bb} = adjustment factor for block effect of local buses that stop within intersection area
- f_a = adjustment factor for an area type
- f_{LU} = adjustment factor for lane utilization
- f_{LT} = adjustment factor for left turns in lane group
- f_{RT} = adjustment factor for right turns in lane group
- f_{Lpb} = pedestrian adjustment factor for left-turn movements
- f_{Rpb} = pedestrian-bicycle adjustment factor for right-turn movements

The fourth step is to determine the vehicle speed for each link. This step can be accomplished using HCM Equation 30-4. This portion of the chapter also contains equations for computing link traversal time (Equation 30-5), link traversal time for free-flow conditions (Equation 30-6), zero-flow control delay for signalized intersections (Equation 30-7), and a calibration parameter which enables the traversal time equation to predict the mean speed of traffic when demand is equal to capacity (Equation 30-8).

$$S = \frac{L}{R + (D/3600)} \qquad (30\text{-}4)$$

where
- S = link speed (mi/h),
- L = link length (mi),
- R = link traversal time (h), and
- D = node delay for link (s).

$$R = R_0 + D_0 + D_M + 0.25T\left[(X-1) + \sqrt{(X-1)^2 + \frac{16J * X * L^2}{N^2T^2}}\right] \qquad (30\text{-}5)$$

where
- R = link traversal time (h),
- R_0 = link traversal time at link FFS (h),
- D_0 = zero-flow control delay at signalized intersection (h),
- D_M = segment delay between signals (equals zero if no signals)(h),
- N = number of signals (equals zero if no signals)
- T = expected duration of demand (typically 1 h) (h),
- X = link demand to capacity ratio,
- J = calibration parameter, and
- L = link length (mi).

$$R_0 = \frac{L}{S_0} \qquad (30\text{-}6)$$

where
- R_0 = FFS link traversal time (h),
- L = link length (mi), and
- S_0 = link FFS (mi/h).

$$D_0 = (N/3600) * DF * (C/2)\left[1-(g/C)\right]^2 \qquad (30\text{-}7)$$

where
- D_0 = zero-flow control delay at signal (h),
- N = number of signals on link,
- 3600 = conversion from seconds to hours,
- g/C = average effective green time per cycle for signals on link (s)
- C = average cycle length for all signals on link (s), and
- DF = adjustment factor to compute zero-flow control delay (0.9 for uncoordinated traffic-actuated signals, 1.0 for uncoordinated fixed-time signals, 1.2 for coordinated signals with unfavorable progression, 0.90 for coordinated signals with favorable progression, and 0.60 for coordinated signals with highly favorable progression).

$$J = \frac{\left[(R_C - R_0 - D_0 - D_M)^2\right]}{L^2} \qquad (30\text{-}8)$$

where
- J = calibration parameter,
- R_C = link traversal time when demand equals capacity (h),
- R_0 = FFS link traversal time (h), and
- D_0 = zero flow control delay (h)
- D_M = segment delay between signals (h), and
- L = link length (mi).

The final step of this methodology is to determine several performance measures. The intensity, duration, extent, and variability of congestion as well as the accessibility of a facility can be found using the procedures in this HCM chapter and Equations 30-9 through 30-15. Every roadway is classified by facility type as a freeway, multilane highway, two-lane highway, arterial, collector, or local road. Then, the following input factors, which Asheville examines in determining the capacity of a specific roadway, are assigned values: posted speed, free flow speed, grade, number of through lanes, area type (urban or rural), truck percentage, left-turn bays, one-way or two-way traffic flow, and median presence. The input factors and facility type are then coupled together to form a specific set of "capacity-related variables" for the particular roadway. These variables are then input into the appropriate table (out of a possible 50 tables in the Asheville model) that gives the expected capacity for a roadway having any combination of these variables. This capacity is the ultimate capacity for the roadway (boundary between LOS

E and LOS F); thus, the maximum allowable number of vehicles that the roadway can service during a given hour is known.

Triangle Regional Model

NCDOT developed a different model for calculating the theoretical capacity of any roadway within the Triangle region. The Triangle Regional Model for Travel Demand Forecasting identifies four classes of roadways: freeway/expressway, rural arterial, suburban arterial and urban arterial. Within the freeway/expressway category, a road is further classified according to whether it is an interstate, suburban freeway, urban freeway, or rural highway, the number of lanes in one direction of travel, and the posted speed limit. Once a value has been recorded for all of these variables, a chart is examined which reveals the projected service volumes for the particular roadway at LOS D, along with the LOS E peak hour capacity. If the roadway is an arterial, it is classified according to the number of lanes in one direction of travel, whether or not it has a median and turn bays, traffic signal density (number per mile), and the posted speed limit. Once a value has been recorded for each of these variables, a chart is examined which reveals the projected capacity for the particular roadway at LOS D and at LOS E, along with the LOS E peak hour capacity. Overall, there are 99 different possible combinations of these variables in the Triangle model, leading to 99 possible different values for a roadway's "ultimate capacity". As is the case in the Asheville model, a roadway in the Triangle model should be able to handle up to the ultimate capacity value for vehicles per hour and still provide an acceptable level of service to its users.

Cherryville, North Carolina

Recently, NCDOT used Q/LOS software developed by the Florida Department of Transportation to establish a relationship between LOS and capacity for roadways in the Cherryville community. The FDOT software is one current method for determining the LOS thresholds for a given roadway, although some of the assumptions made in the model may not be appropriate for use in states other than Florida. Nonetheless, Cherryville's roadways are classified as either rural arterial, suburban arterial, or urban arterial. The various types of roads are then further stratified according to number of lanes, presence of a median and assumed speed. Using these input variables, the FDOT software can produce a projected AADT and peak hour LOS for any roadway in the Cherryville area.

Various methods for calculating the capacity and LOS have been employed across the state of North Carolina; however, the need for a more unified method is critical. Because predicting capacity and LOS is such a new concept in the transportation field, there were not many avenues found for standardized methods in use throughout the United States. FDOT is the only known state to have such a standardized method; therefore, the research team investigated how their model predicts traffic flow quantities.

Florida Department of Transportation Practice

The Florida Department of Transportation (FDOT) has developed an up-to-date handbook and accompanying software for the analysis of the quality and level of service for any roadway under its jurisdiction. Quality of Service (QOS) is "a traveler-based perception of how well a transportation service or facility operates", where level of service (LOS) is simply "a quantitative stratification of quality of service into six letter grades" (A through F with F being the worst). The handbook and software that FDOT has developed are the first successful, comprehensive, multimodal analysis tools of their kind. However, it is important to note that the FDOT LOS Handbook and Software are intended for use only in planning and preliminary design because they do not contain the tools necessary for operational analysis or final design. Many other documents and methods exist which are more appropriate for such analysis.

The FDOT describes two different levels of roadway analysis: generalized planning and conceptual planning. Generalized planning should be utilized when a quick, rough estimate of the LOS of a roadway is desired because this is a tool based upon broad, statewide research and statewide default values. On the other hand, conceptual planning should be used when it is necessary to determine a more exact, detailed measurement of the LOS of a roadway based upon specific observed or expected roadway variables (rather than statewide default values). Of course, even conceptual planning is much less precise than that found in general operational analysis and design.

FDOT developed a series of Generalized Tables to aid users interested in the general planning stage. These tables are included in their handbook and contain default values that are generally applicable throughout the state of Florida. For more detailed, area-specific planning processes, FDOT developed a conceptual planning software program known as LOSPLAN, which is intended for use in applications like deciding on a design concept or scope of a facility. The program is actually separated into three completely separate programs: ARTPLAN for arterials and other signalized roadways, FREEPLAN for freeways, and HIGHPLAN for uninterrupted-flow highways. Also, while the Generalized Tables and LOSPLAN are capable of producing multimodal LOS values (pedestrians, bicycles, buses, and automobiles), they do not produce an overall intermodal LOS that includes all modes. The LOS for each user type is always determined and stated separately from the LOS for the other three modes. For instance, along a given arterial, the automobile LOS may be at level D, but the arterial may possess adequate sidewalk coverage, sidewalk separation from vehicular traffic, and pedestrian crossing times at signalized intersections to provide for a pedestrian LOS of level B.

The FDOT handbook also notes that the term LOS does not directly refer to overall "quality" of trip experience. LOS is a mathematical measurement calculated by engineers and transportation planners that does not deal with other non-numerical factors such as neighborhood safety or appearance. *LOS is intended to be a measure of the level of effectiveness with which a roadway is serving its users, not necessarily a measurement of the "desirability" of a roadway.*

Figure 1-3 (not included here) of the FDOT handbook shows the distinction between a roadway point, segment, facility, corridor, and area. Obviously, a point is the smallest classification of a roadway, indicating just one location that is usually a boundary between segments (e.g., a signalized intersection). The next level of classification is that of a segment, which can be defined as a small portion of roadway defined by two distinct endpoints. *A facility is a significant length of roadway consisting of both points and segments, and is the stratification level at which the FDOT Generalized Tables and LOSPLAN determine LOS.* The next level is the corridor, which is a combination of generally parallel facilities in an area. Finally, an area is defined as a large grouping of all the facilities in a particular geographic region. Because points and segments are the building blocks of facilities, certain analyses within the Generalized Tables and LOSPLAN are performed at these levels. But, as mentioned above, FDOT focuses its LOS analyses on a facility-wide basis.

In keeping with standard traffic engineering practice, most aspects of the LOS analyses conducted via the Generalized Tables and LOSPLAN are based upon the latest industry-wide standard text, the 2000 Highway Capacity Manual. One noteworthy deviation from this practice is that FDOT bases its analysis of two-lane uninterrupted flow highways on results from the 1997 Highway Capacity Manual, because some of the results concerning this particular class of roadway using the 2000 HCM do not seem to correspond correctly to actual collected field data. The Transportation Research Board (TRB) and the American Association of State Highway and Transportation Officials (AASHTO) have responded by funding research to answer two specific concerns about the HCM. First, two-lane highway service volumes have dropped by nearly 50 percent from previous editions. Second, HCM procedures do not appear to be applicable to two lane highways in developed areas. The Midwest Research Institute (MRI) has finished a research project (NCHRP 20-7(160), headed by Doug Harwood) in which they investigated and characterized issues concerning the HCM's analysis procedures. MRI developed recommended changes to the HCM procedures to address these issues, which have been approved by the TRB Highway Capacity and Quality of Service Committee. The reasoning that MRI provided is:

- The service volume issue is present in the directional segment procedure, but not in the two-way segment procedures,
- The service volume issue can be resolved by changes to Equation 20-17 and Exhibit 20-21 in the directional segment procedure, and
- There does not appear to be a problem with the LOS thresholds in Exhibits 20-2 and 20-4.

These findings have resulted in modifications to Equation 20-17 to represent actual conditions for two-lane highways, and other additional minor changes were made as well.

One important aspect of the analysis procedures outlined in the FDOT handbook is that *the procedures rely heavily on the use of averages.* For generalized planning, simple averages for certain traffic variables (such as daily volume) should be used when examining data in the Generalized Tables. On the other hand, *for facility analyses at the conceptual planning level, LOS should be determined based upon examination of averages weighted by segment length.* The primary exception to this rule lies in the treatment of the effective green ratio (how much time, relative to the entire cycle length, may be used for movement in a particular direction at a traffic signal) along arterials. Because a single g/C ratio must be selected for an entire facility, FDOT uses a "weighting" system which gives the effective green ratio at the critical intersection equal effect on the overall g/C ratio's along the corridor. This is achieved by averaging the critical intersection's g/C with the average of all the other signalized intersections along the arterial to arrive at an overall 'weighted average'.

When using the Generalized Tables and/or LOSPLAN, the planner should remember the following two assumptions which were made in developing these tools: 1) mainline non-through movements are adequately accommodated, and 2) all roadway, traffic, and control variables are capacity adjustments, not free flow speed adjustments. The first assumption is of great significance because of the high degree to which it simplifies calculations using many of the input variables for LOS determination. Although it may seem that such a simplification is detrimental to the quality of the analyses, this assumption is necessary at the current time to generate meaningful data for LOS calculations. The second assumption is of lesser importance and is utilized primarily for consistency with general traffic engineering practice and the 2000 HCM calculation processes.

Logically, the most significant aspect of the FDOT Q/LOS Handbook is the description and relative importance of the specific input variables that are used in both the Generalized Tables and LOSPLAN. As does the 2000 HCM, FDOT divides the input variables into three categories: roadway variables, traffic variables, and control (signalization) variables.

Roadway variables deal specifically with physical characteristics of the roadway itself, which may influence user perception of travel quality. Area type refers to whether the roadway is located in an urban area, rural area, or a transitional area (between urban and rural). Number of through lanes is calculated in different places for different types of roadways and certain factors such as add/drop lanes must be taken into consideration when determining an appropriate value for this variable. Roadway class refers to whether the roadway may be considered an arterial, freeway, or other uninterrupted flow facility (e.g., two-lane highway, multilane highway), and must be the first variable determined when preparing to use LOSPLAN. Posted speed is the posted speed limit. Free flow speed is generally considered to be the posted speed plus five miles per hour, although LOSPLAN users may alter this value when appropriate. Roadway length is self-explanatory, although certain general minimum required lengths are suggested for analysis of each roadway type. Left-turn lanes must be classified as either exclusive or shared for analysis purposes. Terrain refers to whether the terrain around the segment is level or rolling, with rolling being considered as a terrain that causes heavy vehicles to reduce their speed below that of passenger cars. Percent no-passing zones is a variable that affects only two-lane highways. Passing lanes refers to whether or not a passing lane is added to improve passing opportunities at certain points along two-lane highways. There are also several roadway variables in the FDOT handbook that specifically relate to bicycles, pedestrians and buses, such as pavement condition, outside lane width, and obstacles to bus stops.

Traffic variables refer to characteristics of the users of the roadway that may affect other users' perception of travel quality. Traffic volume refers to the number of vehicles passing a point on a roadway during a specific period of time. Average annual daily traffic (AADT) refers to the total volume on a roadway segment for an entire year divided by the number of days in the year. Obviously, volume and AADT are not only closely related but are also extremely important in determining vehicular LOS. The planning analysis hour factor (K) is the ratio of the traffic volume in a given hour to the AADT and is generally used for peak hour analysis. The directional distribution factor (D) refers to the proportion of an hour's traffic on a roadway that is going in a particular direction. The peak hour factor (PHF) is the peak hourly volume divided by four times the peak 15-minute rate of flow within the peak hour. Base saturation flow rate and/or capacity refer to the maximum possible steady flow rate of vehicles along a roadway. Percent heavy vehicles (T) refers to the percentage of vehicles on a roadway which have more than four wheels and often varies significantly with the time of day or day of the week. The local adjustment factor or driver population factor allows for a distinction between the types of drivers on the road (e.g., commuters versus tourists). Percent turns from exclusive left turn lanes refers to the percentage of total vehicles at a signalized intersection which are performing left or right turns from exclusive turn lanes. This can be a very important factor in determining the LOS along some arterials. There are also a number of other traffic variables mentioned in the FDOT handbook which do not affect vehicular LOS.

Control variables refer to factors affecting signalization or stop control at an intersection. Obviously, such variables do not apply to freeways or highways and are thus used only in ARTPLAN. Signalized intersection spacing along an arterial is self-explanatory and has a tremendous effect on user perception of quality of travel along many arterials. Arrival type refers to the general quality of progression possible along an arterial rated on a scale of one to six with six being the best and often referring to a pretimed series of signals favoring the peak direction of travel. Signal type simply refers to whether each signal is pretimed, semi-actuated, or fully-actuated. Cycle length is the length of time a signal takes to complete a full sequence of signal phases*;* for actuated signals, the maximum possible cycle length is generally assumed. Effective green ratio (g/C) has already been described in this report and is one of the most important variables in determining the LOS of any arterial because of its huge impact on overall travel time.

For conceptual planning along an urban arterial, the following variables have a highly significant impact on LOS analysis and, therefore, careful consideration should be given for any default value representing them: number of through lanes, left turn lanes, AADT, K, D, signalized intersection spacing, and g/C ratio. Coupled with vehicular volume, these are the most influential variables in most LOS analyses.

The LOSPLAN software is the first successful modeling program of its kind. Although the program is a powerful and somewhat complex tool, it employs an extremely user-friendly format. All three programs, ARTPLAN, HIGHPLAN, and FREEPLAN have the same basic layout. First, a general opening, introductory screen appears. Then, there is a general facility input data screen in which the user can input values for any of the variables that describe the entire facility being analyzed. Next, a segment data input screen appears which enables the user to input values for variables applicable to specific segments within the facility. The program then analyzes all of the input data and puts forth a LOS results screen that shows the overall LOS values for the entire facility as well as for each segment within the facility. Finally, a screen displaying the service volume table for the maximum possible service volumes based on the input data is shown.

Overview of Research Approach

The focus of this project was to produce a software tool utilizing HCM methodologies applicable to planning analyses with North Carolina defaults. From the literature review, LOSPLAN was the most comprehensive tool available, with extensive features and capabilities, including output in the form of a report. The research team desired to produce a more intuitive tool with a graphical interface and plot of MOE against AADT. Such a tool has been developed and is called the North Carolina Level of Service (NCLOS) program.

Developing the NCLOS program involved three primary steps. The first step was a comprehensive analysis of the sensitivity of input factors on the MOE for the four highway types presented in the program. The second step required determining default values for the input variables. Once into this part of the project, an extension of the effort lead to establishing best and worst case values for the input factors, in addition to default values. The research team also reviewed truck count data at 100 continuous count stations across the state for help in establishing truck percentages. The third step was development of the software program, the graphical interface, and the visual plot of MOE versus AADT. The team also provided a link between the analysis results and TransCAD® for use in determining capacity values for planning applications.

These three steps are described in the next three sections and are supported by Appendices B and C, which provide additional detail on the sensitivity analysis and the software program, respectively. Appendix A describes the HCM methodology programmed into the software for determining the MOE for each of the four highway types.

SENSITIVITY ANALYSIS

Creating a software package that met the needs of the NCDOT Transportation Planning Branch required understanding the sensitivity of all variables used in planning analysis software. Sensitivity describes how much of an effect individual variables or factors have on the facilities' Level of Service (LOS). Many variables account for the changes in a facilities operation, such as number of lanes, lane width, grade, length of grade, free flow speed, g/C ratio, interchanges/mile, and number of access points, just to name a few.

Upon reviewing the 2000 HCM many variables and unknowns required further research to determine just how sensitive they really were. Because this analysis is crucial to the backbone of the software, the research team needed to determine default values that could appropriately reflect the type of roadway and its associated variables, thus giving the software user reasonable estimates with which to plan. Some sensitivity analysis was summarized from the 2000 HCM; however, the research team conducted the majority of the analysis for consistency with all types of variables used. The 2000 HCM gives adequate data with which to project default values for two lane highways, therefore, no further sensitivity research was needed on this type of facility.

The sensitivity analysis conducted by the research team was carried out using the 2000 Highway Capacity Software (HCS 2000©) developed by McTrans. HCS 2000© was used because it replicates the procedures within the HCM. Assumptions were made for each variable that was associated with a certain facility type. These assumptions were consistent with the assumptions made in the HCM. Graphically, sensitivity was measured using volume (veh/hr) as the independent variable and the facility's MOE as the dependent variable. By changing one, sometimes two variables (keeping other variables constant) at different volumes, we were able to record the level of service (LOS) at that specific point. The LOS was then plotted at the associated volumes for each variable(s) in question. These graphs showed the range effect for each variable, and thus we could determine the sensitivity of the variable.

Using the HCM documentation, combined with the sensitivity analysis of our research team using HCS 2000©, we were able to determine the sensitivity of a specific variable using three categories: low, medium, or high sensitivity. In short, a low sensitivity variable was one that did not affect the LOS of the facility type on a large scale, a medium one had some variation greater than ± one LOS, and a high sensitivity variable had a very large range throughout the LOS spectrum. Medium and high sensitivity variables were considered for further data collection to obtain good defaults for our planning purposes. Further explanation and graphical analyses of each facility type and the associated variables can be found in Appendix B. A summary of the findings for each variable and facility type is summarized in Table 7 below.

FACILITY TYPE	ATTRIBUTE	SENSITIVITY LEVEL			MORE DATA NEEDED FOR DEFAULTS ?	HOW DATA IS COLLECTED
		H	M	L		
FREEWAYS	Interchanges per Mile			X	No	Entered by the user (site specific)
	% Trucks		X		Yes	Automatic Traffic Recorder (ATR) & Weigh-in-Motion (WIM) sites
	Grade		X		No	Entered by the user (site specific)
	Length of Grade		X		No	Entered by the user (site specific)
	'K' Factor		X		Yes	ATR sites
	'D' Factor		X		Yes	ATR sites
	Free Flow Speed		X		No	
MULTI-LANE HIGHWAYS	Access Points per Mile			X	No	
	Divided / Undivided			X	No	
	Base Free Flow Speed			X	No	
	% Trucks		X		Yes	ATR & WIM sites
	Grade		X		No	Entered by the user (site specific)
	Length of Grade		X		No	Entered by the user (site specific)
ARTERIALS	Exclusive Left Turn Lanes			X	No	
	Median			X	No	
	Urban Class		X		No	
	g/C Ratio	X			Yes	Traffic Engineering Branch
	Signals per mile	X			Yes	GIS - ArcView Data
TWO-LANE HIGHWAYS	Free Flow Speed	X			Yes	Traffic Surveys Unit
	Percent No-Passing Zones	X			Yes	Traffic Engineering Branch
	% Trucks		X		Yes	ATR & WIM sites

Table 7. Sensitivity of Variable by Facility Type

Table 7 shows that for the 21 inputs analyzed for the four facility types, four (4) inputs had high sensitivity, 11 inputs had medium sensitivity, and six (6) inputs had low sensitivity. Also, nine (9) inputs are targeted for additional data collection. Some of this data is available from the Automatic Traffic Recorder (ATR) and Weigh-In-Motion (WIM) traffic collection sites located throughout the state. Other data can be programmed into a planned data collection effort, or, if GIS data layers exist, from specific queries within NCDOT's GIS coverage.

DEFAULT VALUES

The development of the software program took the form of a visual display of AADT plotted against the MOE for each facility type. Figure 4 shows a sample display for freeways. In developing this plot, the research team created a system of input values for three cases: (1) best case, (2) worst case, and (3) default case.

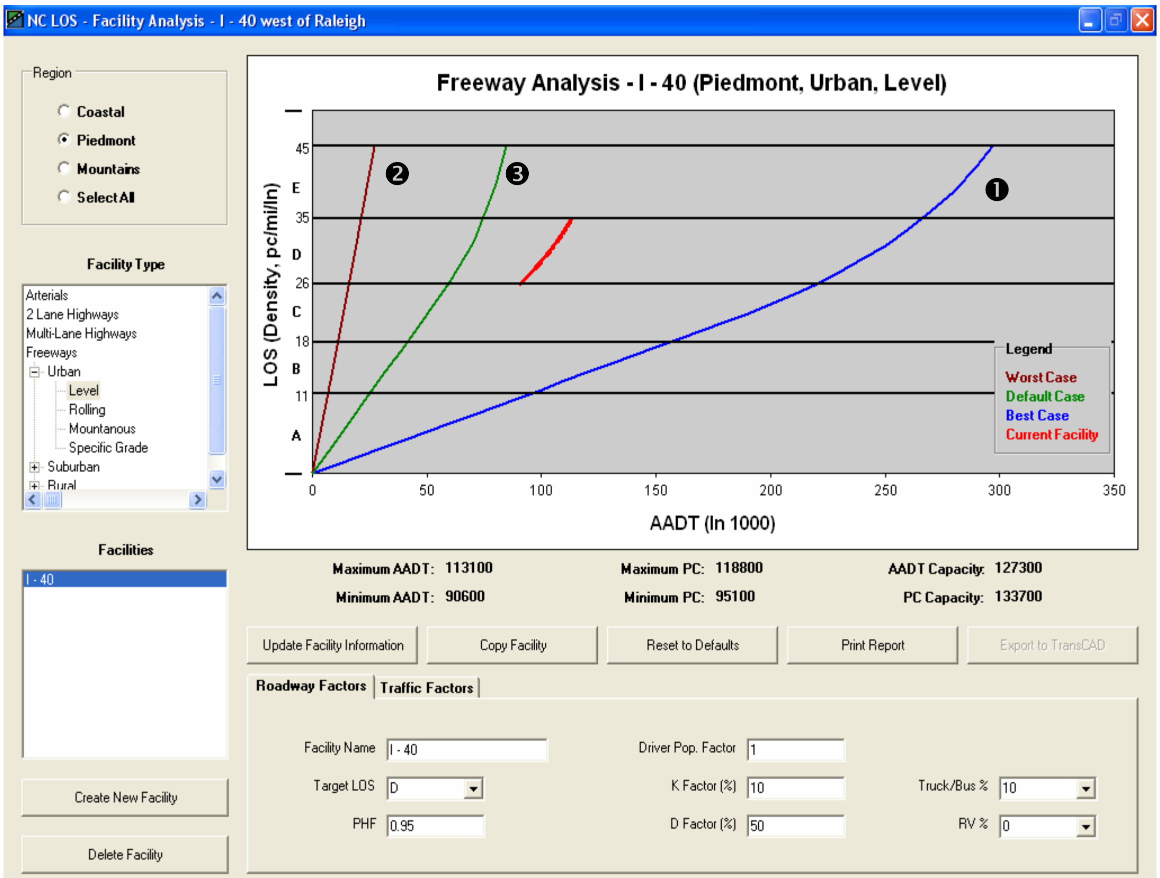


Figure 4. Screen Capture for Freeway Analysis

The best case input values are the required value for each factor that produces the maximum positive affect on the output. Stated another way, the plot of AADT against MOE for the best case scenario results in the highest possible AADT value for a given LOS. Note that in a few cases, the factor is actually increasing in value instead of decreasing if it is used in the denominator of an equation.

The worst case input values are the required value for each factor that produces the maximum negative affect on the output. That is, the plot of AADT against MOE results in the lowest AADT value for a given LOS. Again note that in a few cases, the factor is actually decreasing in value instead of increasing if it is used in the denominator of an equation.

For the default case input values, NCDOT desired to have values for each factor representative of the average facility for urban, suburban, and rural planning analyses in all three regions across the state. Given that each planning analysis could include the three terrain types plus specific grade analyses, a large matrix quickly developed for each of the facility types. Some of the values for the factors were based on judgment of the researchers and the NCDOT staff. However, a few of the factors were based on analysis of traffic count information. For example, NCDOT provided traffic count information for 2002 at 100 continuous traffic count stations located throughout North Carolina. The analysis of the data yielded vehicle classification count numbers that allowed for specific truck percentages to be determined for each region and various facility types (Table 8).

REGION	FUNCTIONAL CLASS	2A-SU	3A-SU	4A-SU	4A-ST	5A-ST	6A-ST	7A-MT	TOTAL TRUCKS*
Coastal	Rural Minor Arterial	4.76%	14.40%	2.14%	2.98%	8.57%	0.24%	0.00%	**33.10%**
Coastal	Rural Principal Arterial - Other	2.89%	1.24%	0.11%	1.73%	4.50%	0.17%	0.02%	**10.65%**
Coastal	Urban Minor Arterial	1.51%	1.06%	0.01%	1.62%	0.20%	0.18%	0.04%	**4.62%**
Coastal	Ubran Principal Arterial	2.52%	0.97%	0.59%	2.84%	3.91%	0.23%	0.04%	**11.10%**
Mountainous	Rural Minor Arterial	3.25%	1.75%	0.15%	1.52%	1.26%	0.21%	0.04%	**8.18%**
Mountainous	Rural Principal Arterial - Interstate	2.85%	2.60%	1.47%	5.37%	16.24%	0.91%	0.18%	**29.63%**
Mountainous	Rural Principal Arterial - Other	2.89%	1.73%	0.35%	1.79%	4.41%	0.20%	0.03%	**11.39%**
Mountainous	Urban Minor Arterial	2.17%	2.19%	0.42%	2.22%	1.20%	0.38%	0.08%	**8.66%**
Mountainous	Ubran Principal Arterial - Other	2.15%	1.50%	0.21%	1.30%	1.18%	0.18%	0.04%	**6.56%**
Piedmont	Rural Minor Arterial	3.21%	1.20%	0.19%	1.78%	4.97%	0.15%	0.01%	**11.52%**
Piedmont	Rural Principal Arterial - Interstate	2.34%	1.25%	0.78%	4.12%	19.82%	0.38%	0.09%	**28.78%**
Piedmont	Rural Principal Arterial - Other	2.69%	1.53%	0.25%	2.21%	7.67%	0.29%	0.04%	**14.67%**
Piedmont	Urban Minor Arterial	2.04%	0.83%	0.05%	1.03%	0.54%	0.06%	0.01%	**4.55%**
Piedmont	Urban Principal Arterial - Other	2.58%	1.93%	0.41%	3.63%	13.50%	0.53%	0.12%	**22.70%**
Piedmont	Urban Principal Arterial - Interstate	2.35%	1.31%	0.18%	1.98%	2.95%	0.23%	0.04%	**9.03%**

* - ' TOTAL TRUCKS ' is the sum of the percentages for the seven classes of heavy trucks (2A-SU through 7A-MT)

Table 8. Truck Percentages

The following pages show the default and other values used to produce the graphs for each of the facility types. The best and worst case values are displayed at the top of each facility type matrix with the default values for each possible scenario listed below. The breakdown of each matrix is first by region, then by location, and finally by surrounding terrain. Note that while the regions (Coastal, Piedmont, Mountains) remain constant across all facility types, the location and terrain categories for arterials are replaced by design category and functional category, respectively, due to the slightly different methodology involved with the arterial class of highways.

Upper / Lower Boundaries

Condition	Hour Factor(K)	Direction Factor(D)	Driver Pop	Truck/Bus %	RV %	Lane Width	Num Lanes/ dir	Lat Clear.(ft)	Intgs/mile	Grade %	Grade Length (mi)
Best Case	0.08	0.5	1	2	0	12	5	6	0	0	0.25
Worst Case	0.2	0.7	0.85	45	5	11	2	2	2	8	2

Default Cases

Region	Facility Location	Terrain	Hour Factor(K)	Direction Factor(D)	Driver Pop	Truck/Bus %	RV %	Lane Width	Num Lanes/ dir	Lat Clear.(ft)	Intgs/mile	Grade %	Grade Length (mi)
Coastal	Urban	Level	0.10	0.50	1	10	0	12	2	6	0.5		
		Rolling	0.10	0.50	1	10	0	12	2	6	0.5		
		Mountainous	0.10	0.50	1	10	0	12	2	6	0.5		
		Specific Grade	0.10	0.50	1	10	0	12	2	6	0.5		
	Suburban	Level	0.12	0.55	1	10	0	12	2	6	0.5		
		Rolling	0.12	0.55	1	10	0	12	2	6	0.5		
		Mountainous	0.12	0.55	1	10	0	12	2	6	0.5		
		Specific Grade	0.12	0.55	1	10	0	12	2	6	0.5		
	Rural	Level	0.15	0.60	1	10	0	12	2	6	0.25		
		Rolling	0.15	0.60	1	10	0	12	2	6	0.25		
		Mountainous	0.15	0.60	1	10	0	12	2	6	0.25		
		Specific Grade	0.15	0.60	1	10	0	12	2	6	0.25		
Piedmont	Urban	Level	0.10	0.50	1	20	0	12	2	6	1		
		Rolling	0.10	0.50	1	20	0	12	2	6	1		
		Mountainous	0.10	0.50	1	20	0	12	2	6	1		
		Specific Grade	0.10	0.50	1	20	0	12	2	6	1		
	Suburban	Level	0.12	0.55	1	20	0	12	2	6	0.5		
		Rolling	0.12	0.55	1	20	0	12	2	6	0.5		
		Mountainous	0.12	0.55	1	20	0	12	2	6	0.5		
		Specific Grade	0.12	0.55	1	20	0	12	2	6	0.5		
	Rural	Level	0.15	0.60	1	25	0	12	2	6	0.25		
		Rolling	0.15	0.60	1	25	0	12	2	6	0.25		
		Mountainous	0.15	0.60	1	25	0	12	2	6	0.25		
		Specific Grade	0.15	0.60	1	25	0	12	2	6	0.25		
Mountains	Urban	Level	0.10	0.50	1	12	0	12	2	6	0.5		
		Rolling	0.10	0.50	1	12	0	12	2	6	0.5		
		Mountainous	0.10	0.50	1	12	0	12	2	6	0.5		
		Specific Grade	0.10	0.50	1	12	0	12	2	6	0.5		
	Suburban	Level	0.12	0.55	1	12	0	12	2	6	0.5		
		Rolling	0.12	0.55	1	12	0	12	2	6	0.5		
		Mountainous	0.12	0.55	1	12	0	12	2	6	0.5		
		Specific Grade	0.12	0.55	1	12	0	12	2	6	0.5		
	Rural	Level	0.15	0.60	1	30	0	12	2	6	0.25		
		Rolling	0.15	0.60	1	30	0	12	2	6	0.25		
		Mountainous	0.15	0.60	1	30	0	12	2	6	0.25		
		Specific Grade	0.15	0.60	1	30	0	12	2	6	0.25		

Table 9. Default Values for Freeways

Upper / Lower Boundaries

Street Class	Condition	Hour Factor (K)	Direct. Factor (D)	PHF	Length (mi)	Num Lanes	Signals / mile	FFS (mph)	Arrival Type	Cycle Length (s)	g/C ratio	% Left Turns
I	Best Case	0.08	0.5	0.85	3	4	0.5	55	5	270	0.7	20
	Worst Case	0.2	0.7	0.95	3	2	2	45	1	90	0.3	2
II	Best Case	0.08	0.5	0.85	2	4	1	45	5	240	0.7	20
	Worst Case	0.2	0.7	0.95	2	2	5	35	1	70	0.3	5
III	Best Case	0.08	0.5	0.85	2	4	4	35	4	200	0.6	20
	Worst Case	0.2	0.7	0.95	2	2	10	30	1	70	0.3	5
IV	Best Case	0.08	0.5	0.85	1	4	6	35	4	180	0.6	20
	Worst Case	0.2	0.7	0.95	1	2	12	25	1	60	0.3	5

Default Cases

Region	Design Category	Functional Category *(Urban Street Class)*	Street Class	Hour Factor (K)	Direct. Factor (D)	PHF	Length (mi)	Num Lanes	Signals / mile	FFS (mph)	Arrival Type	Cycle Length (s)	g/C ratio	% Left Turns
Coastal	High Speed	Principal	I	0.15	0.65	0.90	3	2	0.8	55	3	200	0.60	5
	Suburban	Principal	II	0.15	0.60	0.90	2	2	3	45	3	150	0.55	8
		Minor	II	0.12	0.60	0.90	2	2	3	40	3	120	0.55	8
	Intermed.	Principal	II	0.12	0.55	0.92	2	2	3	40	4	150	0.50	12
		Minor	III / IV	0.12	0.55	0.92	2	2	8	35	4	120	0.50	15
	Urban	Principal	III / IV	0.10	0.50	0.92	1	2	8	35	4	120	0.42	15
		Minor	IV	0.10	0.50	0.92	1	2	10	30	4	90	0.42	18
Piedmont	High Speed	Principal	I	0.15	0.70	0.92	3	2	0.8	55	3	200	0.60	5
	Suburban	Principal	II	0.15	0.65	0.92	2	2	3	45	3	150	0.55	8
		Minor	II	0.12	0.65	0.90	2	2	3	40	3	120	0.55	8
	Intermed.	Principal	II	0.12	0.55	0.92	2	2	3	40	4	150	0.50	12
		Minor	III / IV	0.12	0.55	0.92	2	2	8	35	4	120	0.50	15
	Urban	Principal	III / IV	0.10	0.50	0.92	1	2	8	35	4	120	0.42	15
		Minor	IV	0.10	0.50	0.92	1	2	10	30	4	90	0.42	18
Mountains	High Speed	Principal	I	0.15	0.65	0.90	3	2	0.8	55	3	200	0.60	5
	Suburban	Principal	II	0.15	0.60	0.90	2	2	3	45	3	150	0.55	8
		Minor	II	0.12	0.60	0.90	2	2	3	40	3	120	0.55	8
	Intermed.	Principal	II	0.12	0.55	0.92	2	2	3	40	4	150	0.50	12
		Minor	III / IV	0.12	0.55	0.92	2	2	8	35	4	120	0.50	15
	Urban	Principal	III / IV	0.10	0.50	0.92	1	2	8	35	4	120	0.42	15
		Minor	IV	0.10	0.50	0.92	1	2	10	30	4	90	0.42	18

Table 10. Default Values for Arterials (Urban Streets)

Upper / Lower Boundaries

Condition	Hour Factor(K)	Direction Factor(D)	Driver Pop	Truck/Bus %	RV %	Lane Width	Num Lanes/ dir	Total Lat. Clear.(ft)	Median Type	Access Points / mile	Grade %	Grade Length (mi)
Best Case	0.08	0.5	1	2	0	12	3	12	D	0	0	0.25
Worst Case	0.2	0.7	0.85	20	5	10	2	0	U	40	8	2

Default Cases

Region	Facility Location	Terrain	Hour Factor(K)	Direction Factor(D)	Driver Pop	Truck/Bus %	RV %	Lane Width	Num Lanes/ dir	Total Lat. Clear.(ft)	Median Type	Access Points / mile	Grade %	Grade Length (mi)
Coastal	Urban	Level	0.10	0.50	1	5	0	12	2	8	D	30		
		Rolling	0.10	0.50	1	5	0	12	2	8	D	30		
		Mountainous	0.10	0.50	1	5	0	12	2	8	D	30		
		Specific Grade	0.10	0.50	1	5	0	12	2	8	D	30		
	Suburban	Level	0.12	0.55	1	8	0	12	2	10	D	20		
		Rolling	0.12	0.55	1	8	0	12	2	10	D	20		
		Mountainous	0.12	0.55	1	8	0	12	2	10	D	20		
		Specific Grade	0.12	0.55	1	8	0	12	2	10	D	20		
	Rural	Level	0.15	0.60	1	10	0	12	2	12	D	10		
		Rolling	0.15	0.60	1	10	0	12	2	12	D	10		
		Mountainous	0.15	0.60	1	10	0	12	2	10	D	10		
		Specific Grade	0.15	0.60	1	10	0	12	2	12	D	10		
Piedmont	Urban	Level	0.10	0.50	1	10	0	12	2	8	D	35		
		Rolling	0.10	0.50	1	10	0	12	2	8	D	35		
		Mountainous	0.10	0.50	1	10	0	12	2	8	D	35		
		Specific Grade	0.10	0.50	1	10	0	12	2	8	D	35		
	Suburban	Level	0.12	0.55	1	10	0	12	2	10	D	25		
		Rolling	0.12	0.55	1	10	0	12	2	10	D	25		
		Mountainous	0.12	0.55	1	10	0	12	2	10	D	25		
		Specific Grade	0.12	0.55	1	10	0	12	2	10	D	25		
	Rural	Level	0.15	0.60	1	12	0	12	2	12	D	10		
		Rolling	0.15	0.60	1	12	0	12	2	12	D	10		
		Mountainous	0.15	0.60	1	12	0	12	2	10	D	10		
		Specific Grade	0.15	0.60	1	12	0	12	2	12	D	10		
Mountains	Urban	Level	0.10	0.50	1	5	0	12	2	8	D	25		
		Rolling	0.10	0.50	1	5	0	12	2	8	D	25		
		Mountainous	0.10	0.50	1	5	0	12	2	8	D	20		
		Specific Grade	0.10	0.50	1	5	0	12	2	8	D	25		
	Suburban	Level	0.12	0.55	1	8	0	12	2	10	D	15		
		Rolling	0.12	0.55	1	8	0	12	2	10	D	15		
		Mountainous	0.12	0.55	1	8	0	12	2	10	D	10		
		Specific Grade	0.12	0.55	1	8	0	12	2	10	D	15		
	Rural	Level	0.15	0.60	1	10	0	12	2	12	D	10		
		Rolling	0.15	0.60	1	10	0	12	2	12	D	10		
		Mountainous	0.15	0.60	1	10	0	12	2	10	D	10		
		Specific Grade	0.15	0.60	1	10	0	12	2	12	D	10		

Table 11. Default Values for Multilane Highways

Upper / Lower Boundaries												
Condition	Class	Hour Factor(K)	Direction Factor(D)	BFFS	Truck/Bus %	RV %	Lane Width	No Passing Zone %	Lat. Clear.(ft)	Access Points / mile	Grade %	Grade Length (mi)
Best Case	I	0.08	0.5	60	0	0	12	0	6	0	0	0.25
Worst Case	I	0.2	0.8	60	20	5	9	100	0	40	8	2

Default Cases														
Region	Facility Location	Terrain	Class	Hour Factor(K)	Direction Factor(D)	BFFS	Truck/Bus %	RV %	Lane Width	No Passing Zone %	Lat. Clear.(ft)	Access Points / mile	Grade %	Grade Length (mi)
Coastal	Urban	Level	I	0.10	0.50	60	5	0	12	20	6	30		
		Rolling	I	0.10	0.50	60	5	0	12	20	6	30		
		Mountainous	I	0.10	0.50	60	5	0	12	80	6	20		
		Specific Grade	I	0.10	0.50	60	5	0	12	80	6	20		
	Suburban	Level	I	0.12	0.55	60	8	0	12	20	6	20		
		Rolling	I	0.12	0.55	60	8	0	12	20	6	20		
		Mountainous	I	0.12	0.55	60	8	0	12	80	6	10		
		Specific Grade	I	0.12	0.55	60	8	0	12	80	6	10		
	Rural	Level	I	0.15	0.60	60	10	0	12	20	6	10		
		Rolling	I	0.15	0.60	60	10	0	12	20	6	10		
		Mountainous	I	0.15	0.60	60	10	0	12	80	6	10		
		Specific Grade	I	0.15	0.60	60	10	0	12	80	6	10		
Piedmont	Urban	Level	I	0.10	0.50	60	10	0	12	20	6	35		
		Rolling	I	0.10	0.50	60	10	0	12	20	6	35		
		Mountainous	I	0.10	0.50	60	10	0	12	80	6	30		
		Specific Grade	I	0.10	0.50	60	10	0	12	80	6	30		
	Suburban	Level	I	0.12	0.55	60	10	0	12	20	6	25		
		Rolling	I	0.12	0.55	60	10	0	12	20	6	25		
		Mountainous	I	0.12	0.55	60	10	0	12	80	6	20		
		Specific Grade	I	0.12	0.55	60	10	0	12	80	6	20		
	Rural	Level	I	0.15	0.60	60	12	0	12	20	6	10		
		Rolling	I	0.15	0.60	60	12	0	12	20	6	10		
		Mountainous	I	0.15	0.60	60	12	0	12	80	6	10		
		Specific Grade	I	0.15	0.60	60	12	0	12	80	6	10		
Mountains	Urban	Level	I	0.10	0.50	60	5	0	12	20	6	25		
		Rolling	I	0.10	0.50	60	5	0	12	20	6	25		
		Mountainous	I	0.10	0.50	60	5	0	12	80	6	20		
		Specific Grade	I	0.10	0.50	60	5	0	12	80	6	20		
	Suburban	Level	I	0.12	0.55	60	8	0	12	20	6	15		
		Rolling	I	0.12	0.55	60	8	0	12	20	6	15		
		Mountainous	I	0.12	0.55	60	8	0	12	80	6	10		
		Specific Grade	I	0.12	0.55	60	8	0	12	80	6	10		
	Rural	Level	I	0.15	0.60	60	10	0	12	20	6	10		
		Rolling	I	0.15	0.60	60	10	0	12	20	6	10		
		Mountainous	I	0.15	0.60	60	10	0	12	80	6	10		
		Specific Grade	I	0.15	0.60	60	10	0	12	80	6	10		

Table 12. Default Values for Two-Lane Highways

SOFTWARE PROGRAM

The North Carolina Level of Service (NCLOS) program is an implementation of the 2000 Highway Capacity Manual. The calculations described in the HCM are implemented in the FacilityCalculator.dll component of NCLOS. This DLL allows a developer to externally access the HCM equations implemented by NCLOS. NCLOS includes an interface for the FacilityCalculator.dll. This interface is the FacilityAnalyzer.exe. Upon installation of NCLOS, both the FacilityAnalyzer.exe and the FacilityCalculator.dll are available to users and developers.

NCLOS is broken up into two parts. The first part is the FacilityCalculator.dll and the second is the FacilityAnalyzer.exe. Figure 5 below shows the components of the LOS Analysis program. This diagram displays the exposed interfaces that are used by FacilityAnalyzer.exe. In addition, the FacilityCalculator.dll is a class library that can be used by any number of programs, including TransCAD®.

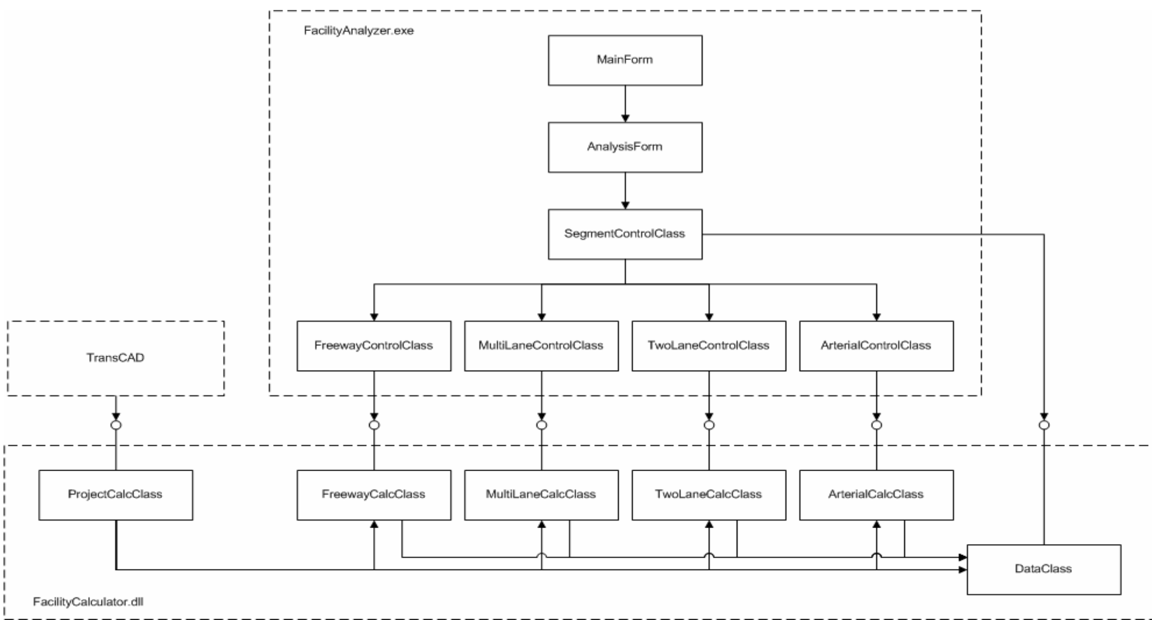


Figure 5. NCLOS Components

FacilityAnalyzer.exe is a MS Windows® executable program containing the interface for NCLOS. This executable accesses FacilityCalculator.dll and is required to run NCLOS. FacilityAnalyzer.exe depends on FacilityCalulator.dll to calculate results along with storing and retrieving data from the database. The majority of this document focuses on FacilityCalculator.dll.

FacilityCalculator.dll can be accessed by any number of applications other than FacilityAnalyzer.exe. Any development environment, including environments for macros and scripts that support OLE calls to DLL's, can be used to access FacilityCalculator.exe. This DLL was designed specifically for use with TransCAD® by the NC DOT. A detailed breakdown of the programming used to develop the NCLOS software is located in Appendix C.

Below is the tutorial for NCLOS that can be printed directly from within the program by the user. The tutorial gives an introduction to the layout and design of the program as well as detailed instructions on how to perform an analysis. *Please note: the information below is from the actual text of the tutorial and therefore any graphs, references, or figures noted may not coincide with those mentioned throughout the rest of this report.*

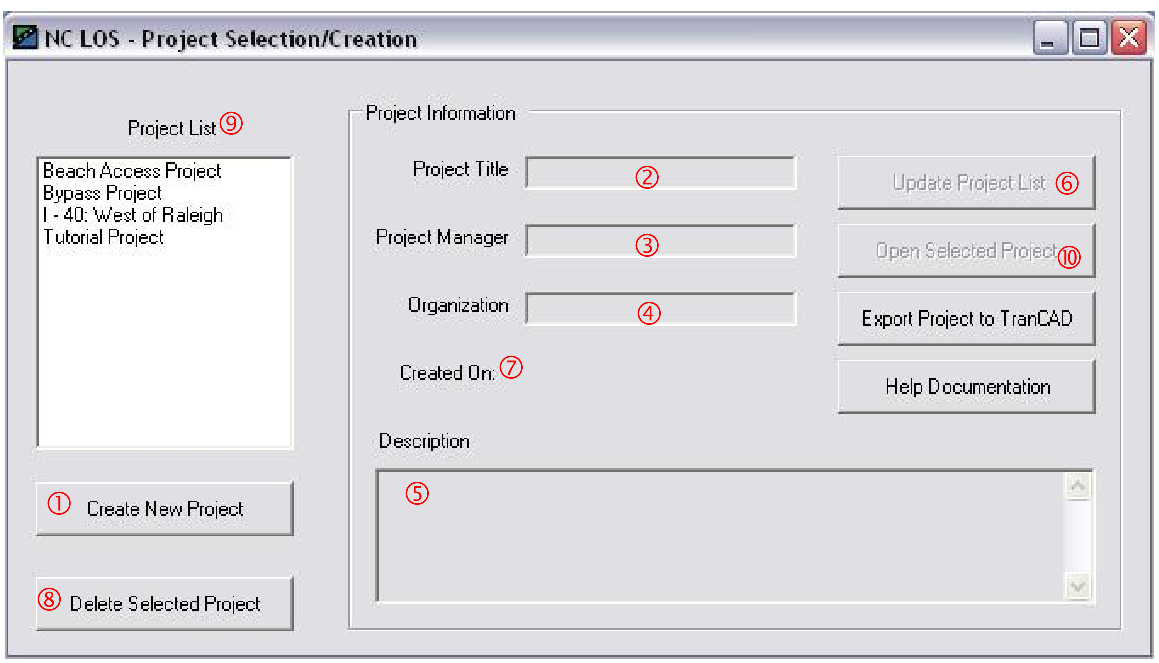
PROGRAM TUTORIAL

A. INTRODUCTION

Welcome to the North Carolina Level of Service (NCLOS) program tutorial. The following information will introduce you to the various functions and options contained within NCLOS as well as explain some of the methodologies behind its look and design. While the tutorial will explain the basic workings of the program, it will not cover every single aspect and option; it only introduces you to the basics of how to use the program by reviewing freeway analysis. Extensive help is available within the program by right clicking on a word/title to get a pop-up help box.

B. PROJECT SELECTION/CREATION

The first screen that you will see when the NCLOS program begins is the *Project Selection / Creation* page:



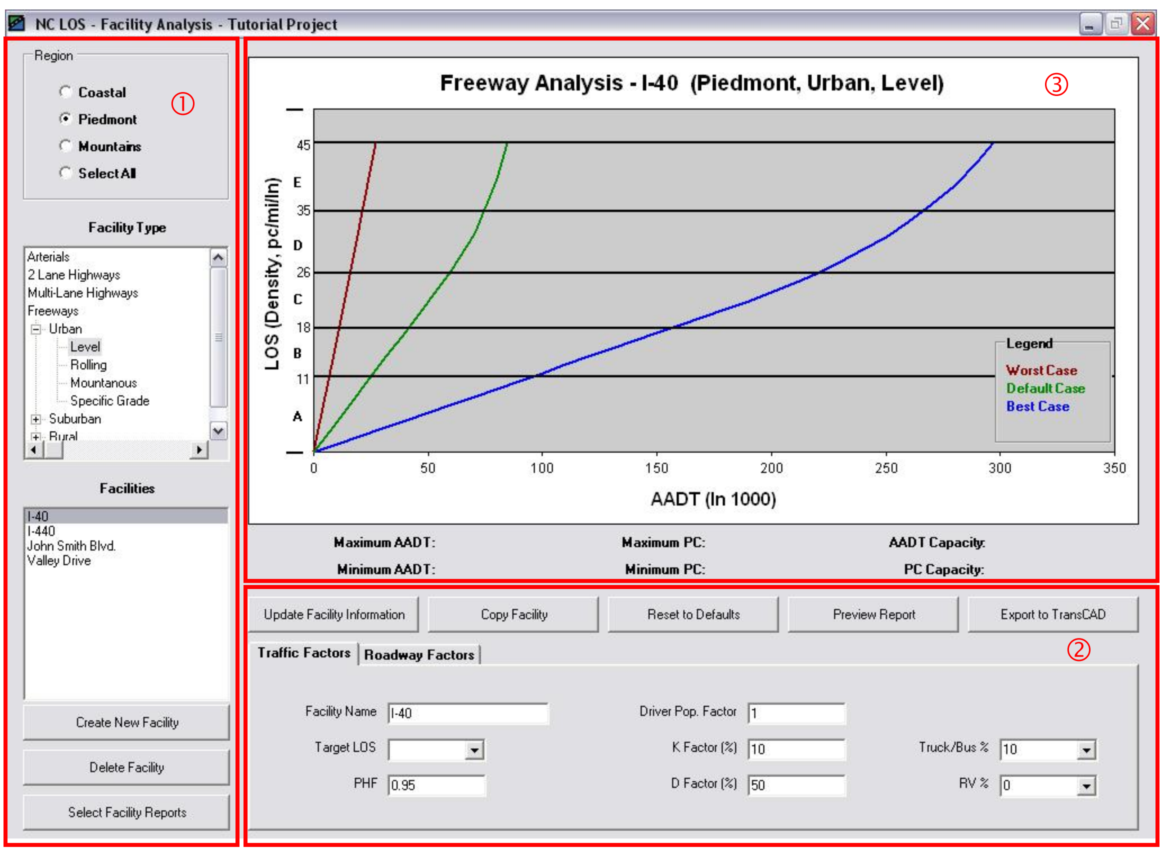
On this screen you have the option of either creating a new project file or opening an existing project file.

1. Creating a new project file

To create a new project file click on the button labeled *Create New Project*①. Once this option has been selected you will be prompted to enter some information for the newly created project, including the project title②, the name of the project manager③, the organization④ that is carrying out the analysis, and, if desired, descriptive information on the project in the box labeled *Description*⑤, e.g., analysis of various options for new beach access road in Brunswick County. Once you have finished entering the project information, make sure to click *Update Project List*⑥ (which will become active once a project is created) to save the newly created project. Additionally, a *Created On* date⑦ is automatically produced for the newly created file at this time as well. If you wish to delete a project at any time, just select the project in the *Project List* box⑨ and then click *Delete Selected Project*⑧.

2. Opening a project

Once you have created a project and you wish to open it, or to open a pre-existing project, you must highlight the desired project in the *Project List* box⑨ on the upper left hand side of the previous screen and then click *Open Selected Project*⑩ on the right hand side of the screen. This takes you to the *Facility Analysis* screen:



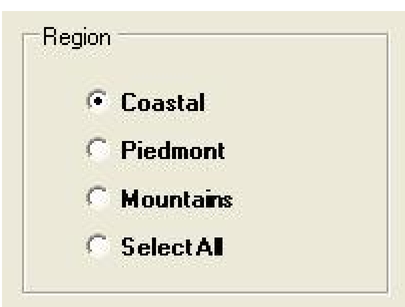
C. USING THE FACILITY ANALYSIS SCREEN

The *Facility Analysis* screen is the heart of the NCLOS program. It is used for all analyses carried out within the program, as well as for the creation, deletion, and copying of facilities, the printing of reports and the exporting of data to TransCAD®. Below is a brief overview of the *Facility Analysis* screen followed by more detailed explanations of its components and functions.

The *Facility Analysis* screen is broken up into three major parts. The first part is the far left hand side of the screen① where existing facilities are chosen and new ones are created. This portion of the screen also contains an inventory, located in the box labeled *Facilities*, of all the facilities within the current project file. The second part, located in the bottom portion of the whole screen②, is made up of two menus (accessible by the *Roadway Factors* and *Traffic Factors* tabs) which contain all of the attributes for the facility being analyzed and buttons for various operations within the program such as the printing of reports and the exporting of data to TransCAD®. Finally, the third part of the whole screen③ is the graphical and numerical output of the analysis. It is comprised of the large graph field in the upper right portion of the screen and the corresponding data output for Average Annual Daily Traffic (AADT), Passenger Cars (PC) and PC at Capacity, which are all located directly beneath the graph field. All of these fields are blank until analysis is performed.

1. Navigating the region menu

The *Region* menu, located in the upper left corner, allows you to select the region of North Carolina in which you are performing analysis; Coastal, Piedmont or Mountains.



For example, if you want to see all of the existing facilities located within the Piedmont region of your project, then you would simply select the button labeled *Piedmont* and then only facilities that were in the Piedmont area would be displayed in the *Facilities* box in the bottom left portion of the screen. To view all of the facilities within a project, regardless of region, just select the option labeled *Select All* and the *Facilities* box would then list all of the facilities for the active project.

Note that the regions represent more of a demographic/cultural/economic effect on the analysis and not so much the effect of terrain or the environment around a facility. For example, if you were doing an analysis in Wilmington (Coastal region) and a mountain suddenly appeared one day, you would still use the Coastal region for analysis and not the Mountains region because the Coastal region represents the default values for the eastern portion of the state which has different travel patterns, travel composition, driver populations, etc., when compared to the Mountains region in the western portion of the state. Terrain type is instead taken into account as an input parameter for all analyses where you can select the appropriate terrain or specific grade for your facility.

2. Navigating the facility type menu

Once you have selected the region you wish to work within, you then go to the *Facility Type*① menu to select the type of facility you wish to analyze. Your initial option is to select one of four facility types: Arterials, 2-Lane Highways, Multilane Highways or Freeways. Once you select a facility type, the tree view then expands to the next level of options. From this second level onward, the tree view is not identical for all facility types as they each have their own definitions and terminologies. For example, in the screenshot on the left below, which could perhaps be a project in the Raleigh area, *Freeways* was chosen at the root level, then an *Urban* setting was selected and finally, a *Level* terrain was chosen. Whereas for arterials (screenshot on the right below), the second tree level is slightly different, with an additional option of the four classes of arterials (*High-Speed, Suburban, Intermediate, and Urban*) and for the third level the options of either *Principal Arterial* or *Minor Arterial under Arterial/Intermediate.*

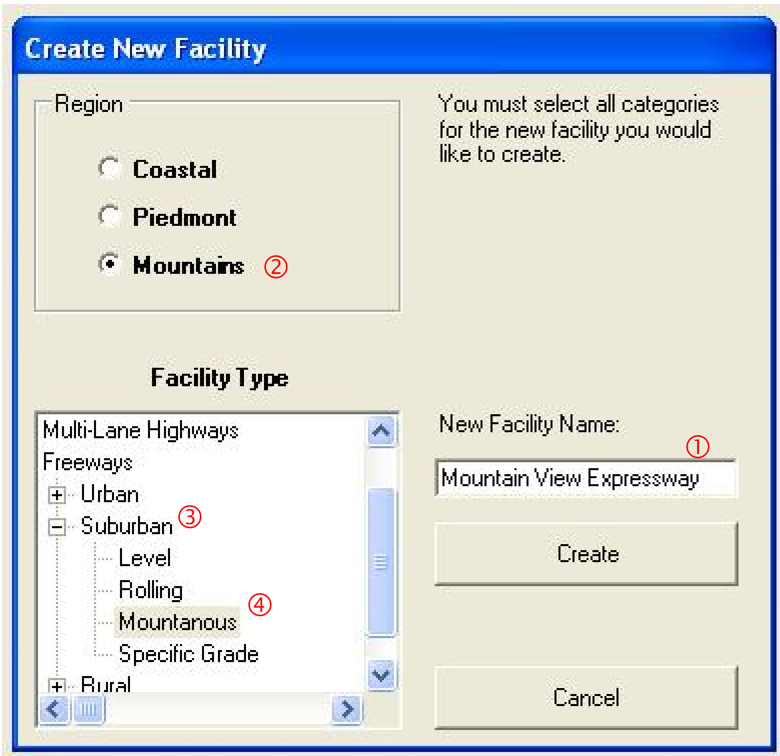
Also, as each tree level is selected, the *Facilities* box② changes to show only those facilities that meet the selections you have chosen. For example, in the left screenshot above, there might have been twenty freeway facilities listed in the *Facilities* box initially, but after the *Urban* and *Level* criteria were selected there were only two facilities, I-40 and I-440, that matched all of the selected requirements (Piedmont region → Freeway facility type → Urban environment → Level terrain)

3. Opening an existing facility

To open an existing facility, click on its name in the *Facilities* box②. Remember, the *Facilities* box only shows those facilities that match the requirements you have selected in the tree view under *Facility Type*①. If you currently have the tree view on *Multilane Highways* then all multilane highways for that project will be listed; but if you have expanded the tree view to select *Multilane Highways* and *Urban*, then only multilane highways in an urban setting will be displayed in the *Facilities* box.

4. Creating a new facility

Creating a new facility requires selecting the *Create New Facility* button near the bottom left corner of the facility analysis screen. Once it is selected a dialog box will popup prompting you to select the criteria for the facility that you are creating:



For example, in this screenshot, the user is creating a freeway facility named "Mountain View Expressway"① in the Mountains region of the state②, in a Suburban setting③ with Mountainous surrounding terrain④. Once all of the criteria in the tree view are selected and the name of the facility is entered, click on *Create*⑤ and the facility is then added to the *Facilities* box and saved in the project file.

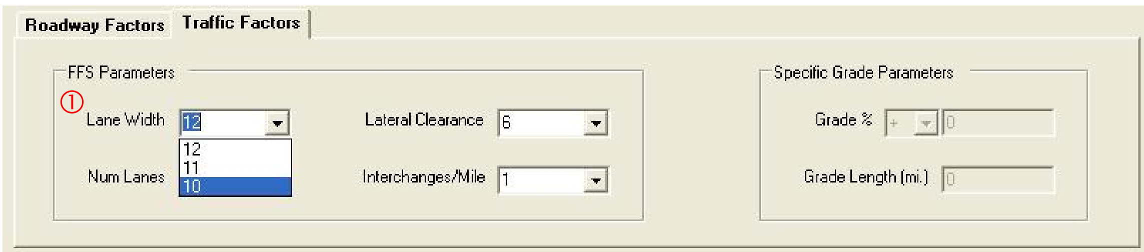
Additionally, there is a shortcut that can be utilized when creating several similar facilities. The tree view in the *Create New Facility* dialog box opens at the same level as the current tree view on the main *Facility Analysis* page. If you need to create several facilities similar to the "Mountain View Expressway" in the example above, you can go to Mountains, Freeway, Suburban, Mountainous on the main page, then hit *Create New Facility*, and each facility you create would already have Mountains, Freeway, Suburban, Mountainous selected, so you would simply have to enter each facility name and hit *Create* each time.

5. Operating the roadway and traffic factors tabs

Each of the four facility types have their own characteristics and default values which have been broken down into two main categories, *Roadway Factors* and *Traffic Factors*. To switch between the two categories simply click on their respective tabs near the bottom portion of the *Facility Analysis* page.

- Changing facility characteristics -

When a facility if first created, each of its characteristics is set to its default value based on the facility's region, facility type, setting and terrain. The user sees these values pop up but is then able to change any or all of the characteristics as he or she sees fit. There are two main ways to change characteristics: (1) using a drop down menu or (2) entering a value in a data entry field. The drop down menu is employed when there are set options for the characteristic that is being altered. For example, in the screenshot below, the user is changing the lane width① on a freeway facility from the default value of 12-feet.

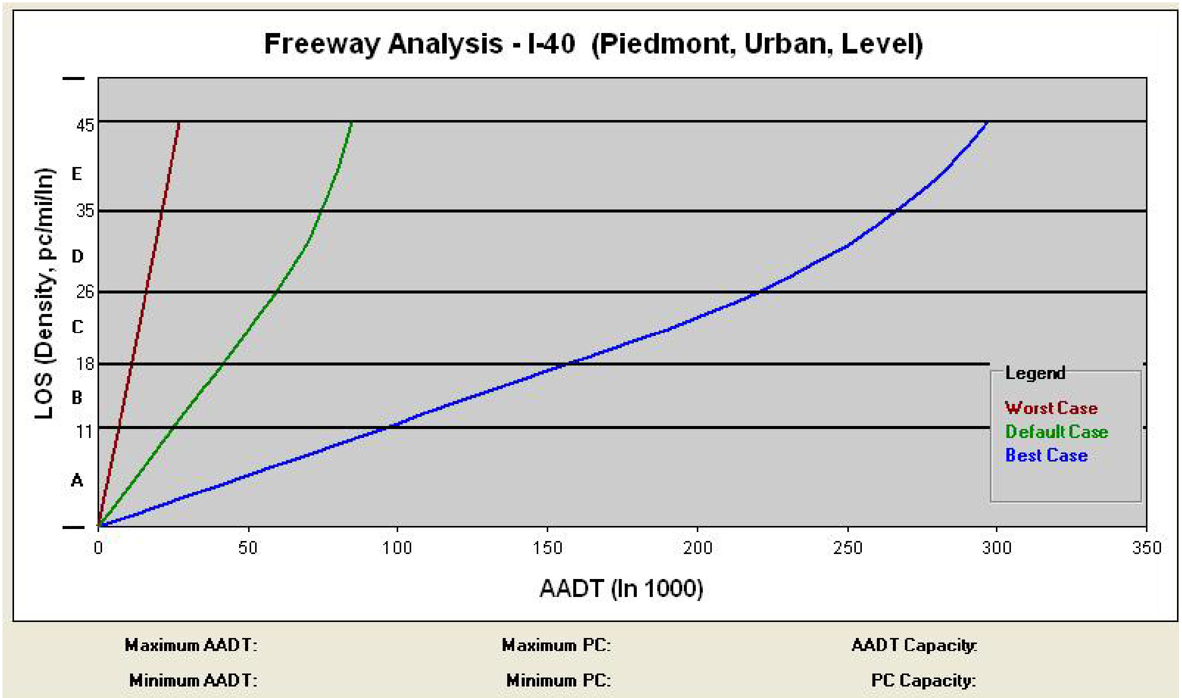


In this case, the only options available other than 12-feet are 11-feet and 10-feet. The user cannot enter any other value, such as 10.5-feet or 13-feet.

The other method to change a characteristic is to use a data entry field. For these characteristics, there are no set options for the user; he or she can enter any value that is appropriate. However, most of the characteristics with data entry fields do have some set range of values that the entered number must be between. For example, PHF does have a data entry field, but the number must be between 0.5 and 1.0 with the user able to enter any number within that range, such as 0.53 or 0.85.

6. Executing the program and interpreting the results

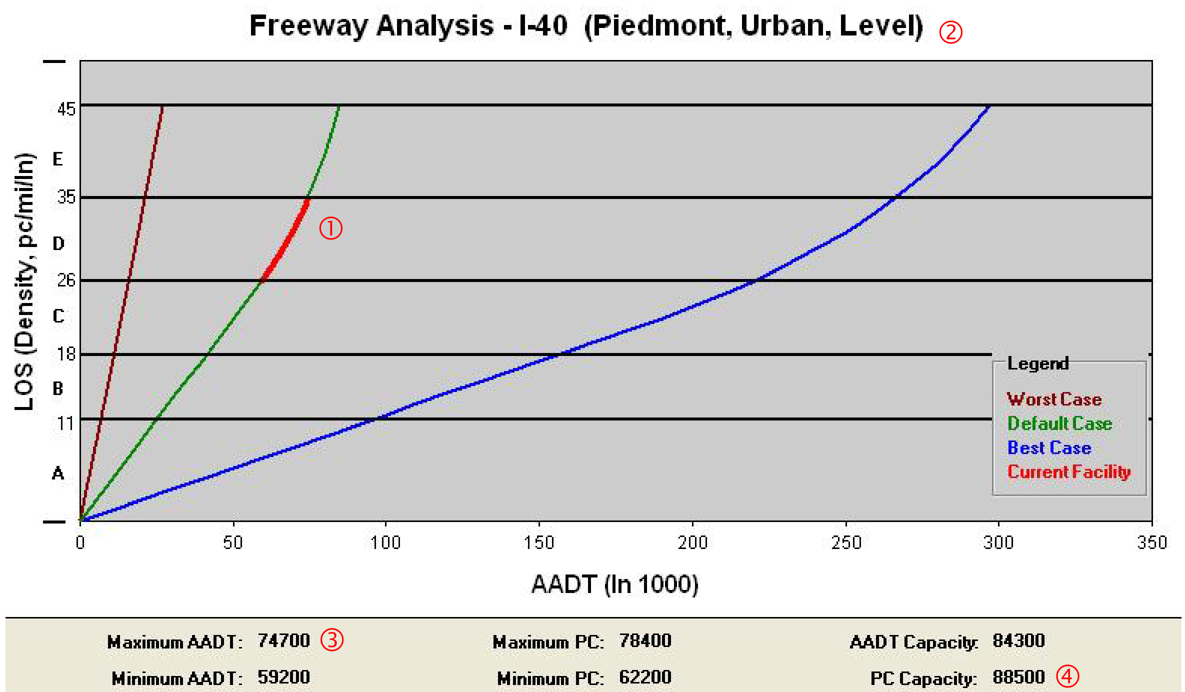
The program graphically displays the results calculated from the methodology presented in the Highway Capacity Manual, allowing the user to evaluate various 'scenarios' or 'options' for different facilities. For example, what volume of traffic can a freeway handle and still operate at LOS D if an additional lane is added? What if two lanes are added? While the actual numerical results are displayed as well, the graphical nature of the program allows the user to quickly determine what effect various roadway/traffic modifications have on a particular facility. This is achieved through the use of a desired LOS, which is used to base your planning decisions around, and through the use of three curves that are present on all facility graphs: a 'Best Case curve', a 'Worst Case curve', and a 'Default Case curve'. The freeway graph below is an example.



The purpose of the three curves is to provide a 'reference' for the analysis results. When a facility is first created, and none of its characteristics have been modified, the analysis results follow the 'default curve'. But as soon as any of the characteristics are modified, then volume either increases or decreases from the default calculation in proportion to the effect of the change. However, only the portion of curve within the selected LOS value is displayed in red. More will be said about this later.

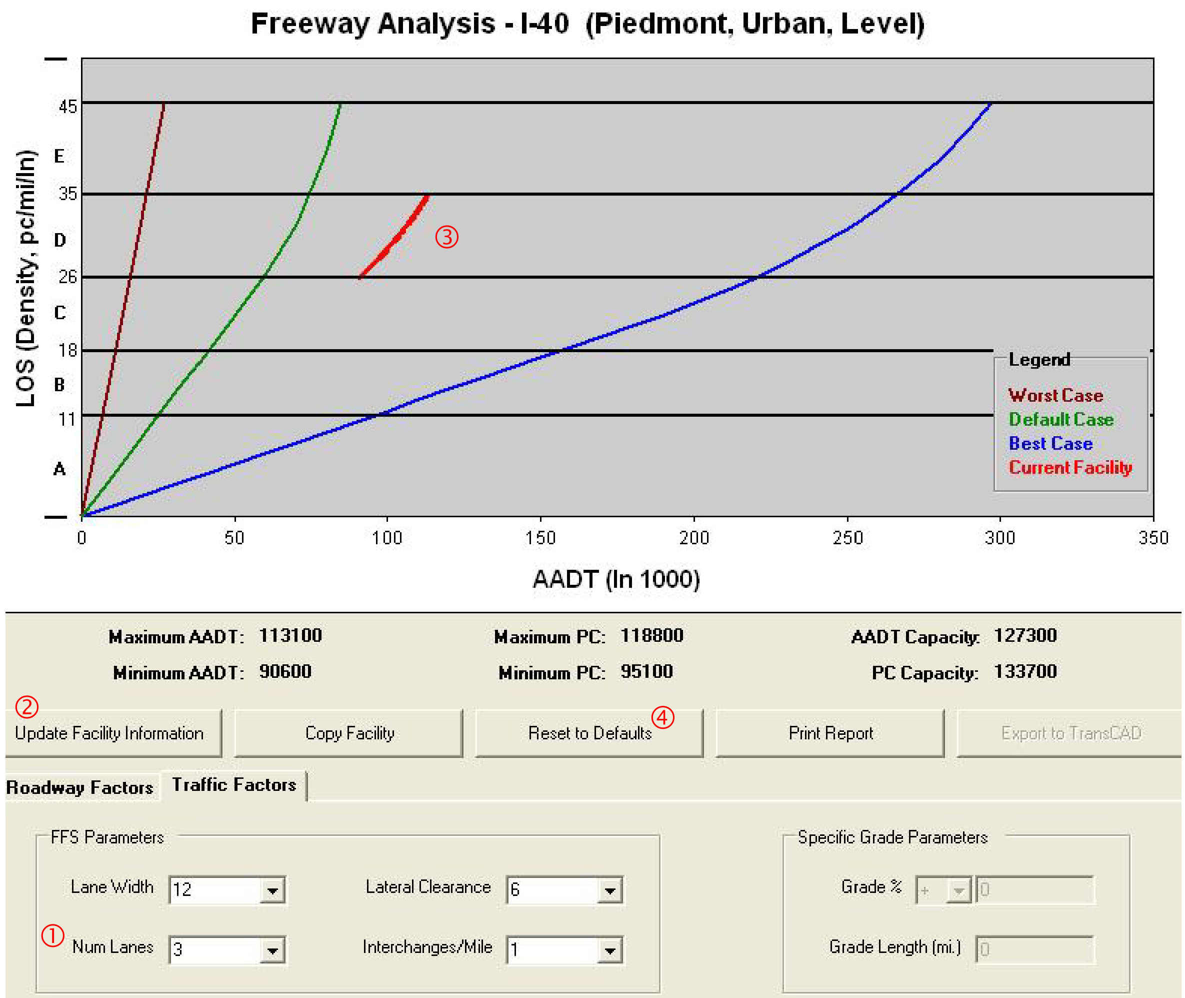
This graphical format allows the user to quickly gauge the impact of whatever characteristic they modified. For example, did adding a lane move the results very far to the right or just a little bit? What affect would losing 4 feet of shoulder to put in a sidewalk have on the capacity of the roadway?

For demonstration, using the freeway graph above, if LOS of D is selected as the desired LOS and none of the defaults are modified you would get the following results:



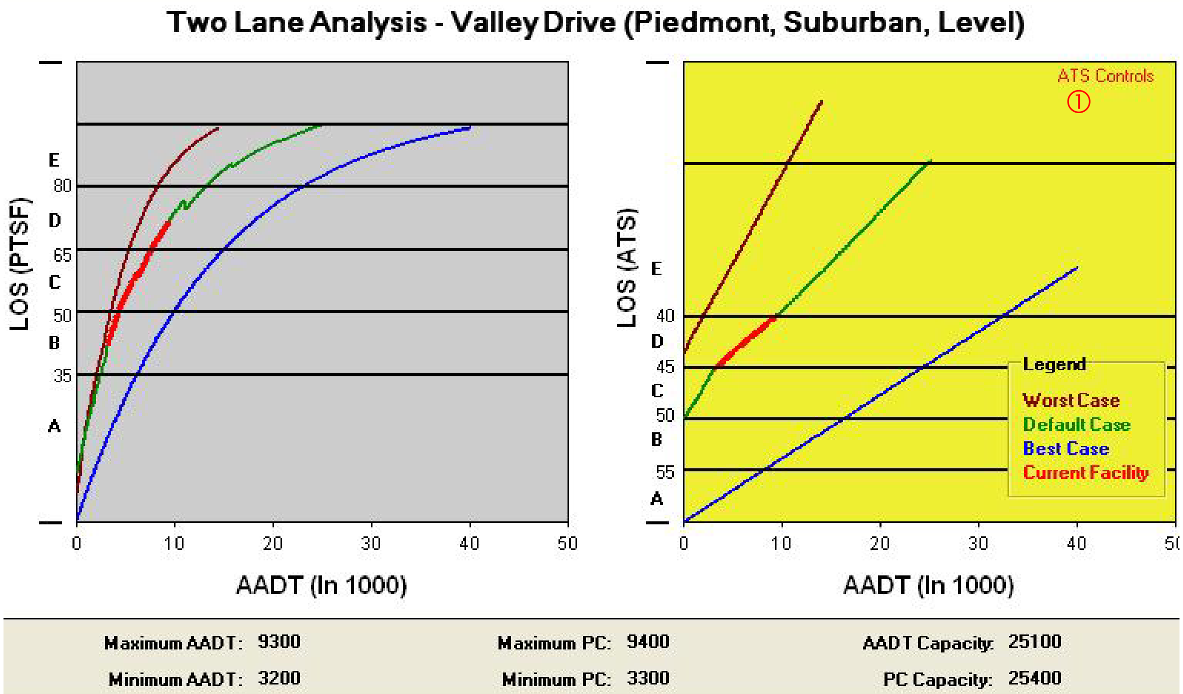
As you can see, this results in a small portion of red curve① being displayed on the default curve within LOS D. Thus, for a default freeway, in the piedmont region, in an urban setting with level terrain②, the maximum AADT that the roadway can handle and remain within LOS D is 74,700 vehicles③ and the <u>capacity</u> of that roadway at maximum LOS E in passenger cars per day is 88,500④.

If you wanted to determine the effect of adding an additional travel lane in each direction to that same roadway, all click on the Traffic Factors tab and go to the *Number of Lanes*① selection box and change it from two lanes to three lanes and then select *Update Facility Information*② to view the new results:



As you can see above, the addition of another travel lane has shifted the analysis results③ to the right, towards the Best Case curve and the numerical values have increased to a maximum AADT for LOS D of 113,100 vehicles (up from 74,700) and a passenger car capacity of 133,700 (up from 88,500). Using this same method, it is possible to change any of the Traffic or Roadway Factors in order to view their effect on the roadway's service volume for a given LOS. Note that you do not have to hit the *Update Facility* button after you modify each characteristic; you can change all the factors required and then hit the *Update Facility* button one time to have the program take all of the modifications into account. Finally, if at any time you wish to have the facility reset to its default conditions, just click on the *Reset to Defaults* button④ to have all of the characteristics return to their initial default values.

Note concerning two-lane highways: Class I two-lane highways have a slightly different interface because there are two measures used to determine LOS: Percent Time Spent Following (PTSF) and Average Travel Speed (ATS). The 'worst case' of the two measures is the one that controls the analysis. For example, if the PTSF for a roadway is at LOS C but the ATS has it at LOS D, then the roadway as a whole is said to be operating at LOS D. The NCLOS handles this by showing both the graph for PTSF and the graph for ATS and then displaying which of the two measures is the controlling factor by shading its graph yellow and by also stating in its upper right corner① that it is controlling.

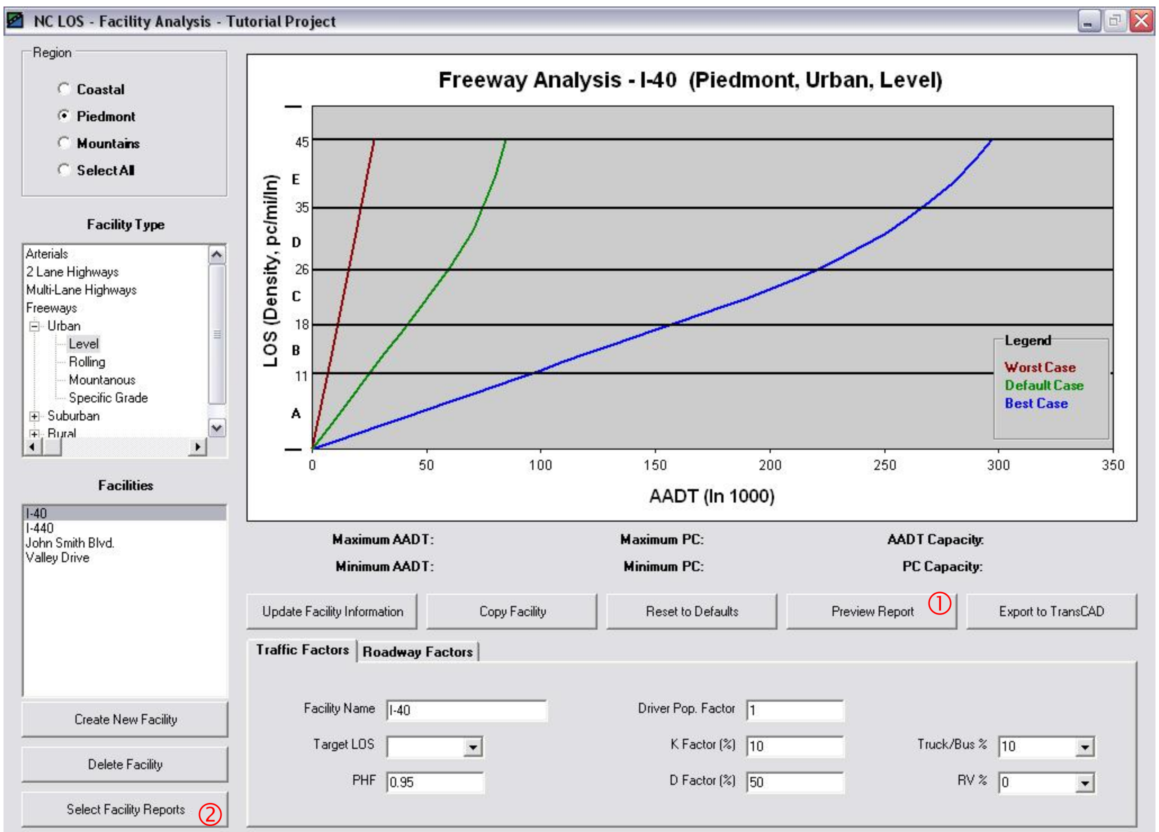


7. Copying/printing a facility

Reports can be viewed and printed for each facility in the selected project. These reports include the basic project information, facility parameters, and the LOS minimums and maximums for each LOS range. Reports can be viewed and printed in two different ways. The first is as a report on a single facility. The second is by selecting any number of reports within a project and then viewing them in a combined report.

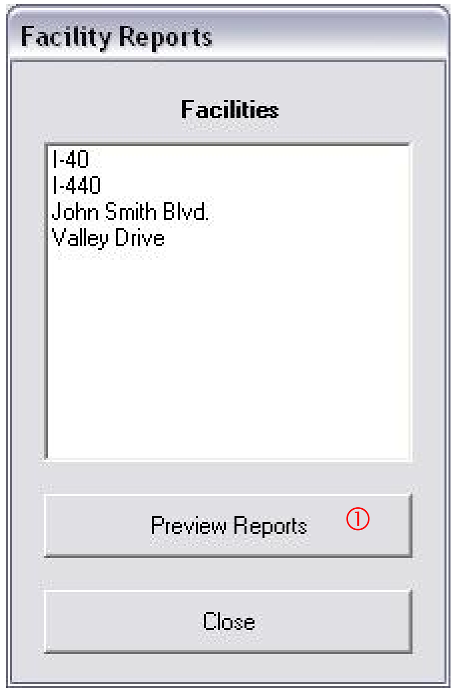
- Single Facility Report -

To view and print a report for a single facility the Facility Analysis window must be opened and a facility must be selected. Once the desired report has been selected a report for this facility can be viewed by left clicking on the *Preview Report*① button. Once this button has been selected a new window will be displayed with a formatted report for the selected facility.



- Multiple Facility Report -

To view and print a report for multiple facilities with a project the Facility Analysis window must be opened. Left clicking on the Select Facility Reports, button will bring up another dialog shown below.

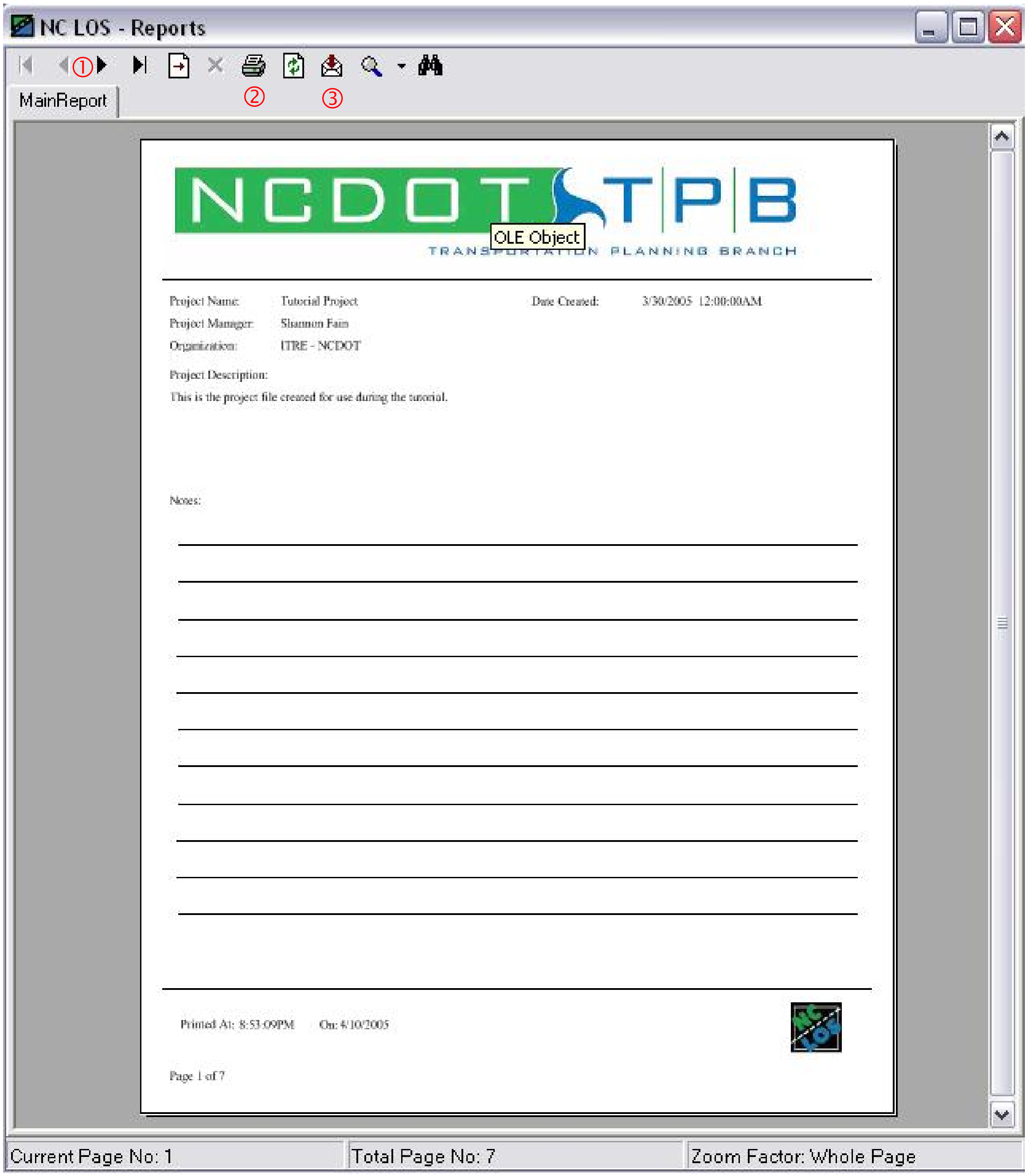


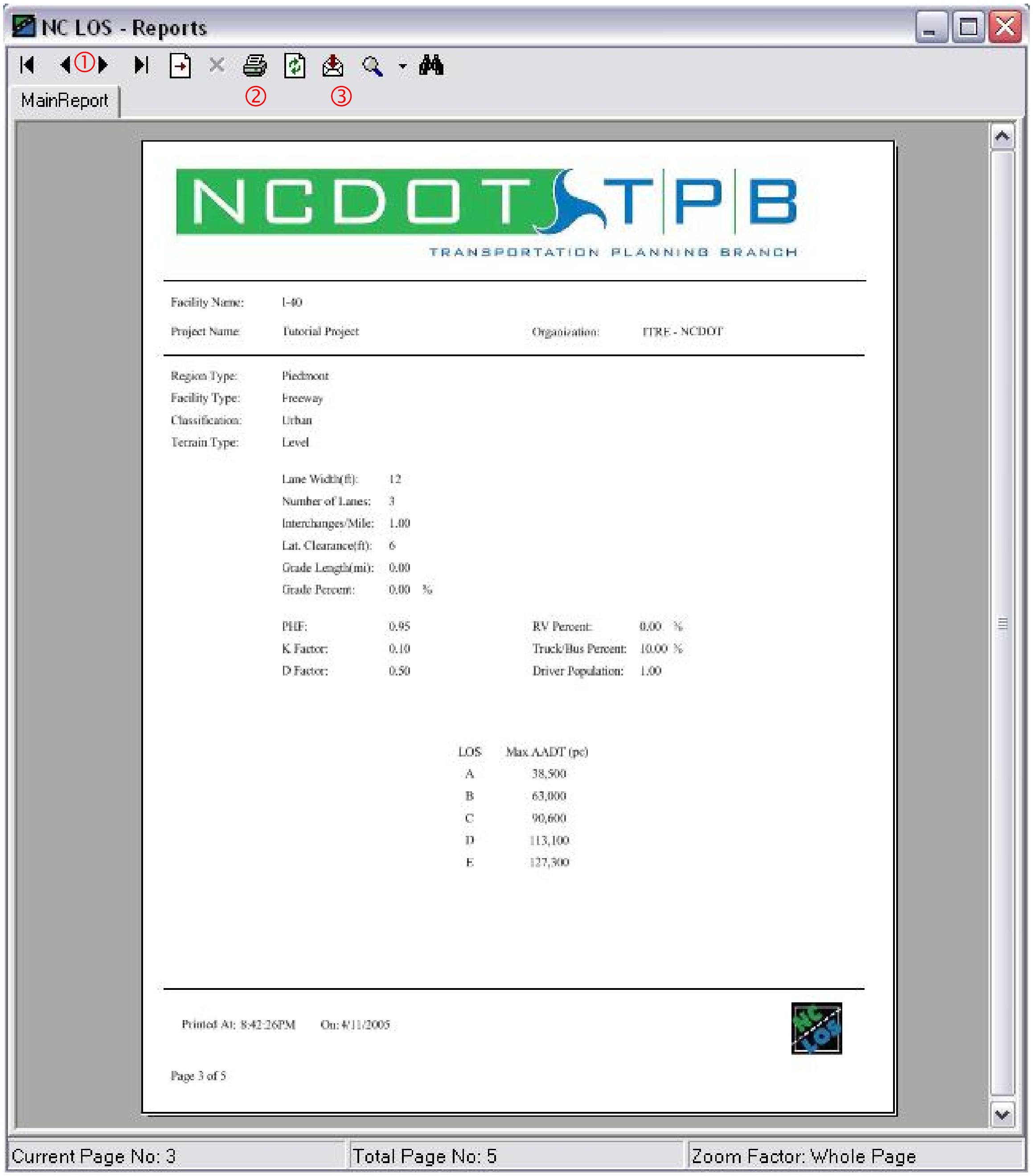
From this dialog any number of facilities can be selected. Once selected, left clicking on the *Preview Reports*① button will bring up a new window displaying a formatted report that includes all of the selected facilities.

To select all the reports for the opened project select the Select All radio button on the NC – LOS Analysis window then left click the Select Facility Reports button. This will bring up the Facility Reports dialog as shown bellow with all of the facilities in the project. Select every facility in the list and left click the *Preview Reports*① button. The resulting report will include every facility in the opened project.

- Viewing and Printing Facility Reports -

One the facilities have been selected and the Preview Report button has been clicked, the Project Report window shown below will open.

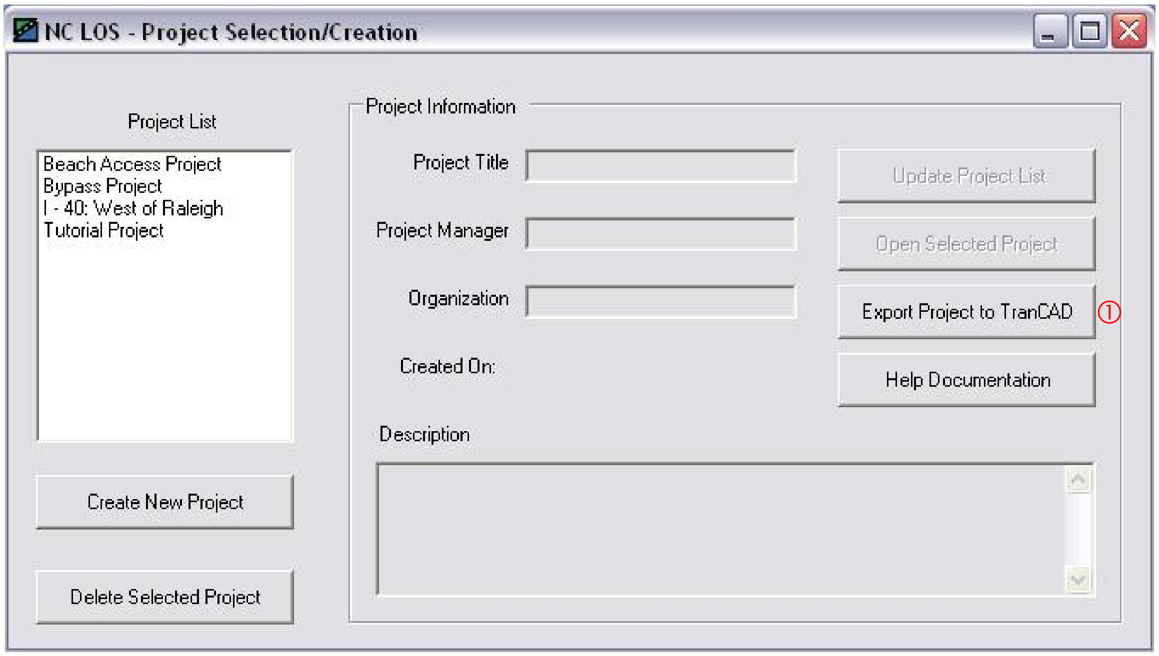




To navigate to different pages in the report use the arrow keys① in the tool bar. The first page list overall project information while the rest of the pages lists the analysis results for the facility or facilities chosen, organized by facility type; i.e. all of the freeway facilities together, all of the multilane facilities together etc. To print the report currently being viewed, click on the *Print*② icon in the tool bar at the top of the window. The report can also be exported to a file using the *Export*③ button. Reports can export to several different file formats to be viewed or emailed at a later time, including PDF and Word .doc files.

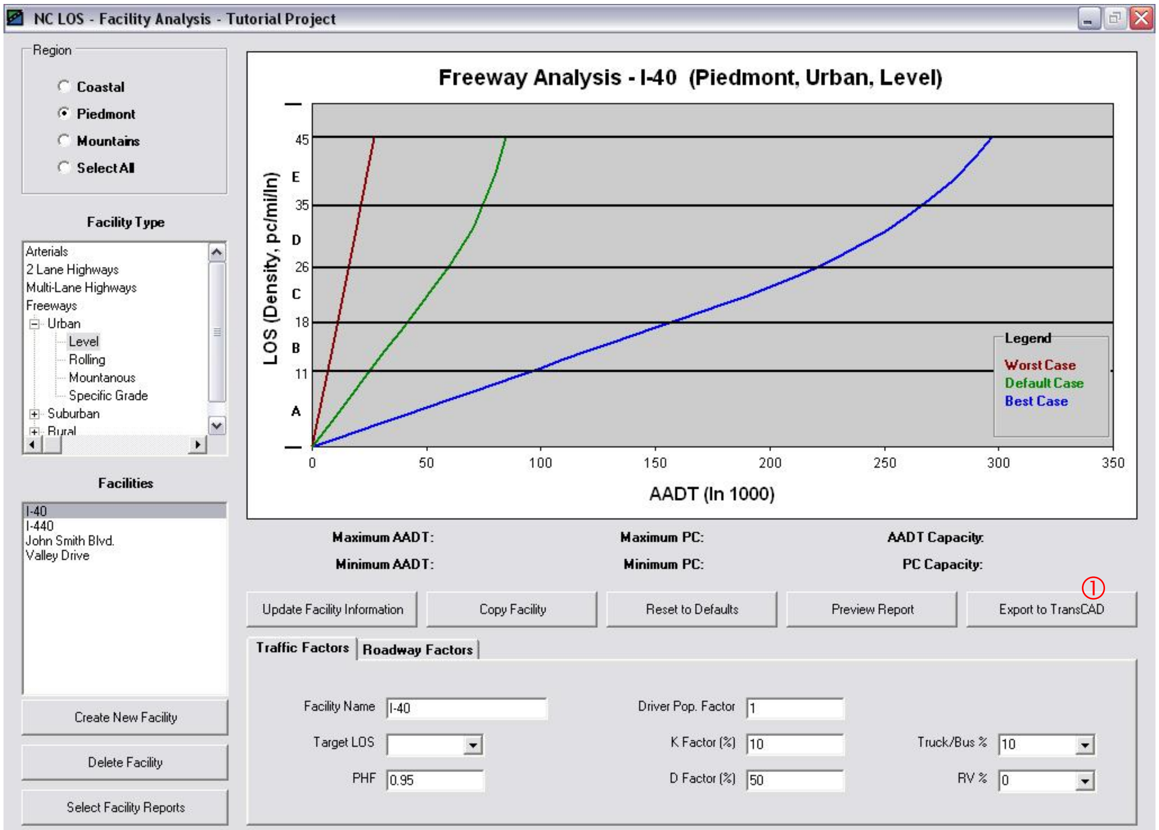
8. Exporting to TransCAD®

There are two ways to export the facilities of a project to a flat file suitable for use in TransCAD® or other similar programs. The first way is to export an entire project from the Project Selection/Creation window. Exporting an entire project is accomplished by selecting a project and then clicking on the *Export Project to TransCAD*① button shown below.



Clicking on this button will bring open a file save dialog box where you select a directory and filename to which to write the data. The information is written to the file in comma-delimited format. This file can be read by most GIS applications.

The second way to export a facility is to do it individually, one facility at a time. To export a single facility, open the project that contains the facility and then select the facility you wish to export.



Once a facility has been selected, it can be exported by clicking on the *Export to TransCAD*① button shown above. Clicking on this button will bring open a file save dialog box where you select a directory and filename to which to write the data. The information is written to the file in comma-delimited format. This file can be read by most GIS applications.

END OF TUTORIAL

The tutorial describes the functionality built into the NCLOS program. The unique graphical display, ease of changing input values, and available output options make this program a valuable supplement for planning analyses.

A final issue concerning the development of the software program had to do with inconsistencies that were found in the plots of AADT versus 'percent time spent following' (PTSF) and 'average travel speed' (ATS) for two-lane highways. Due to the grade adjustment values and passenger car equivalent values given by the 2000 HCM Exhibits 20-7 through 20-10, plots showed that at several points a slightly higher AADT produced a lower PTSF and a higher ATS. This was inconsistent with the nature and intent of the equations and produced a 'saw tooth' effect at the volume threshold points when plotted. It was determined that this saw tooth effect was largely a result of the dramatic change in value of the adjustment factors from one range of flow rates to another. In compensating for this problem, the adjustment factors in HCM Exhibits 20-7 through 20-10 were interpolated using a weighted average. The interpolation for each table took the following form:

AADTPercent = (V - MinV) / (MaxV - MinV)

AdjValue = ((MaxAdj - MinAdj) * AADTPercent) + MinAdj

where:

V	= Flow rate (pc/hr)
MinV	= Minimum flow rate for the range in which V is located (pc/hr)
MaxV	= Maximum flow rate for the range in which V is located (pc/hr)
AADTPercent	= Point at which V is located, between MinV and MaxV (%)
AdjValue	= Adjustment factor to be used in calculations
MaxAdj	= Maximum adjustment factor for the range in which V is located
MinAdj	= Minimum adjustment factor for the range of V

The result of this averaging was a smooth plot of the MOE versus AADT, which the research team viewed as the intent of the methodology.

FINDINGS AND CONCLUSIONS

The primary result of this project is the development of a new, user-friendly program for calculating capacities for future highway projects. This new tool is geared specifically to North Carolina by populating geometric and traffic defaults with values representing average conditions throughout the state. Using the 2000 HCM as the backbone for the calculations, a graphical interface was developed that allows rapid, visual feedback on various planning options and their effect on the LOS and capacity for a particular highway segment.

The visual aspect of the program, particularly the ‘framing’ provided by the best and worst cases on each graph, lends itself to a more intuitive manner of output recognition. The user can attempt various “what if” scenarios by altering the input values to represent possible design considerations for each particular highway. Although the main result of the program is this graphical interface, the program also enables the user to produce a numerical report detailing the results of his or her analysis as well as the ability to export the calculated capacity to the TransCAD® system model.

Secondary products related to the project include the development of default data for various regions, highways types, environments, and system characteristics present throughout the state. These defaults were based on both data provided by the Department and the collective expertise and experience of the Transportation Planning Branch staff and the research team. In addition, a comprehensive sensitivity analysis was performed on the data required for capacity analysis by the 2000 HCM methodology to determine which properties, or characteristics, exhibited a high, medium, or low effect on the overall performance of the roadway. This sensitivity analysis may prove to be a vital reference resource in the future, particularly when looking at data collection efforts and how to maximize their effectiveness. For example, those characteristics for which highway performance is deemed to be highly sensitive could receive a larger proportion of the data collection effort in the future, or may even receive further attention in the form of additional research into how to more accurately and thoroughly collect the ‘sensitive’ data.

RECOMMENDATIONS

The project team recommends that the NCLOS program be utilized by the TPB staff to determine capacities and service volumes for various highway types throughout the state. The program will allow for these values to be determined in a consistent, user-friendly manner, geared specifically for conditions prevalent to the highway systems of North Carolina. Training in the program will be provided by the project team, and the included help system and tutorial should enable the TPB staff to perform in-house training for new staff members.

The project team also recommends that the NCLOS program be used by the TPB in conjunction with their TransCAD® model development efforts to import values from a common capacity analysis source for use with the model. Currently, the capacity values used for TransCAD® come from a variety of sources ranging from generalized tables to the experience of the analyst. Use of the NCLOS program will help generate values for this process which are based upon specific regional and local factors for a particular highway, but which are also accurate and reproducible for comparing two or more separate roadway segments.

A final recommendation of the project team is that the sensitivity analysis performed during the project be considered when the Department carries out future data collections efforts to ensure that the characteristics determined to have a substantial impact on the performance of a highway are collected. This would allow for the default values to be updated in a manner specific to North Carolina and its particular regions and environments.

IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

The NC Level of Service (NCLOS) program was created to meet the needs of the NCDOT Transportation Planning Branch for their travel demand modeling efforts. Without accurate representations of capacity and level of service on various facilities in the several regions of the State, travel demand models will lose much of their effectiveness. The completion of this project provides a substantial enhancement to the Department's planning efforts.

PRIMARY PRODUCTS

User-friendly software program – allows for the determination of service levels and capacities for various roadway facilities from basic roadway, geographic, and traffic data.

SECONDARY PRODUCTS

Input data – once the tool is put into use by the TPB, the software will provide input data (capacity values) in the form of link attribute information for travel demand models.

Several final copies of the program will be produced on CD and handed over to the TPB for their use and distribution as needed. Multiple training sessions are scheduled to familiarize the branch staff with the workings of the program and to enable future in-house training by the TPB to new staff members. The research team's training sessions will cover all aspects of the program including installation, startup, the program's file system, use of the various facility types and their respective outputs, the printing of reports, as well as TransCAD® data exportation. Some training slots will be available for selected NCDOT staff from other branches, such as Highway Design and Traffic Engineering.

CITED REFERENCES

Transportation Research Board (TRB), National Research Council. *"2000 Highway Capacity Manual."* Washington D.C., 2000.

Florida Department of Transportation. "Level of Service Handbook." Tallahassee: 1998, 2001.

Florida Department of Transportation. Software LOS Tables. http://www.dot.state.fl.us/planning/systems/sm/los/los_sw2.htm

NCDOT - NCMIN
North Carolina Multimodal Investment Network
http://www.dot.state.nc.us/planning/statewideplan/ncmin/NCMIN_pg.htm

NCDOT - Triangle Regional Model for Travel Demand Forecasting

FHWA - SPASM
Sketch Planning Analysis Spreadsheet Model.

FHWA - STEAM
Surface Transportation Efficiency Analysis Model
http://www.fhwa.dot.gov/steam/index.htm

TransCAD® is a registered trademark of Caliper Corporation and is the current planning model platform used by NCDOT.

HCS2000© is copyrighted by The McTrans Center, University of Florida.

MS Windows® is a registered trademark of Microsoft Corporation.

Guttenplan, M. "Multi-Modal Level of Service Analysis at a Planning Level." ITE 2000 Annual Meeting and Exhibit, Institute of Transportation Engineers, 2000.

Phillips, R., Karachepone, J., Landis, B. "Multi-Modal Quality of Service Project." Florida Department of Transportation (FDOT), 2001.

APPENDIX A: 2000 HCM FACILITY METHODOLOGY AND CALCULATIONS

Freeways

Figure A1 graphically depicts the methodology for determining LOS on basic freeway segments.

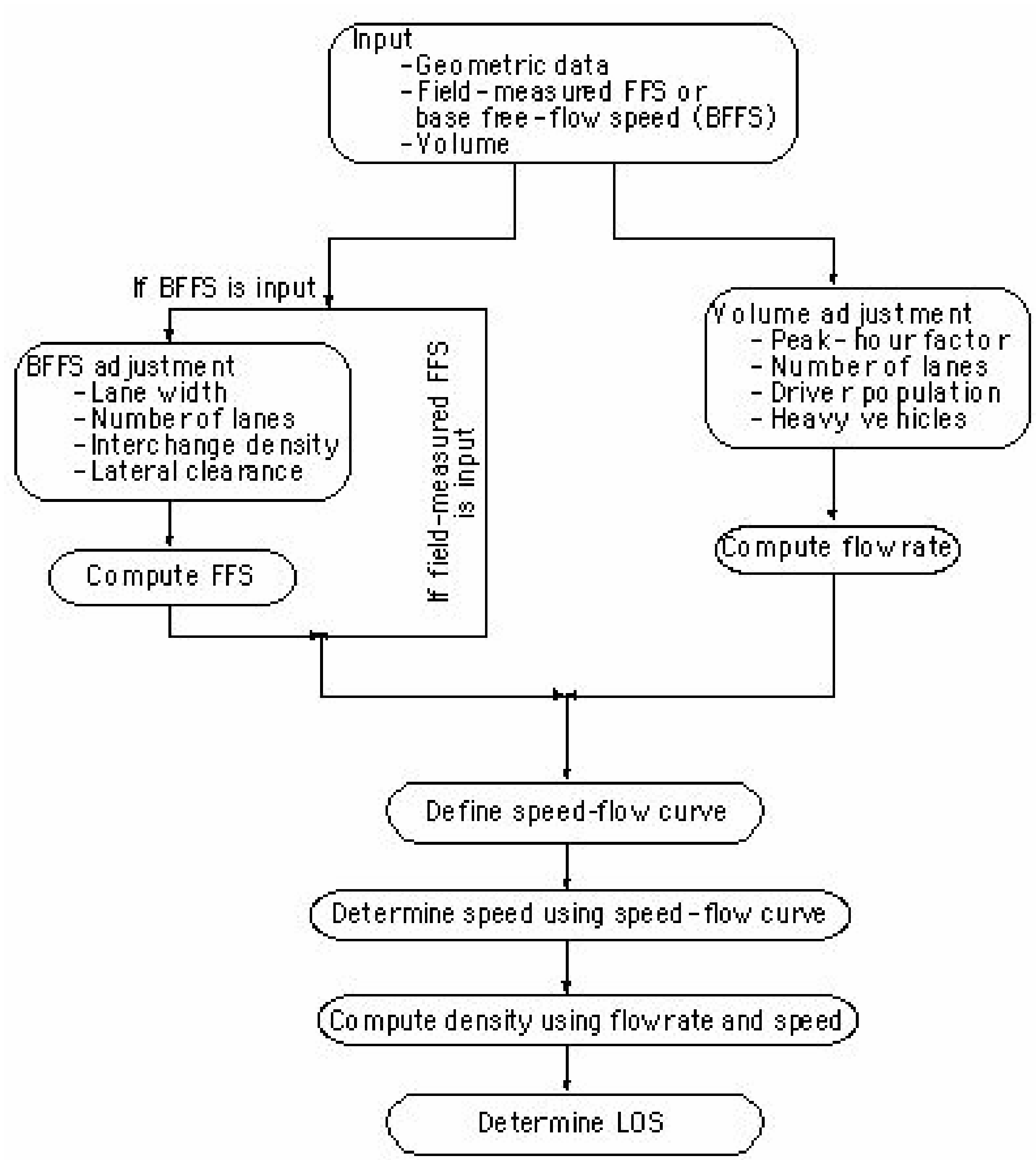


Figure A1. Basic Freeway Segment Methodology (HCM Exhibit 23-1)

LOS for a basic freeway segment is estimated by calculating density. Density can be found using HCM Equation 23-4.

$$D = \frac{v_p}{S} \qquad (23\text{-}4)$$

where

- D = density (pc/mi/ln),
- v_p = flow rate (pc/h/ln), and
- S = average passenger-car speed (mi/h).

LOS criteria for basic freeway segments can also be defined using Table A1, and is also depicted graphically in the summary of Basic Freeways in the Literature Review in Figure 1.

Criteria	LOS A	LOS B	LOS C	LOS D	LOS E
FFS = 75 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	75.0	74.8	70.6	62.2	53.3
Maximum v/c	0.34	0.56	0.76	0.90	1.00
Maximum service flow rate (pc/h/ln)	820	1350	1830	2170	2400
FFS = 70 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	70.0	70.0	68.2	61.5	53.3
Maximum v/c	0.32	0.53	0.74	0.90	1.00
Maximum service flow rate (pc/h/ln)	770	1260	1770	2150	2400
FFS = 65 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	65.0	65.0	64.6	59.7	52.2
Maximum v/c	0.30	0.50	0.71	0.89	1.00
Maximum service flow rate (pc/h/ln)	710	1170	1680	2090	2350
FFS = 60 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	60.0	60.0	60.0	57.6	51.1
Maximum v/c	0.29	0.47	0.68	0.88	1.00
Maximum service flow rate (pc/h/ln)	660	1080	1560	2020	2300
FFS = 55 mi/h					
Maximum density (pc/mi/ln)	11	18	26	35	45
Minimum speed (mi/h)	55.0	55.0	55.0	54.7	50.0
Maximum v/c	0.27	0.44	0.64	0.85	1.00
Maximum service flow rate (pc/h/ln)	600	990	1430	1910	2250

Note:
The exact mathematical relationship between density and v/c has not always been maintained at LOS boundaries because of the use of rounded values. Density is the primary determinant of LOS. The speed criterion is the speed at maximum density for a given LOS.

Table A1. LOS Criteria for Basic Freeway Segments (HCM Exhibit 23-2)

In each of the preceding exhibits, a free-flow speed (FFS) for the facility and the operating conditions of the facility are used to help determine LOS. FFS is the average passenger car speed during low to moderate flows. The best way to find FFS is to measure it in the field. When field measurements are not available, HCM Equation 23-1 can be used to approximate FFS using an assumed Base Free Flow Speed (BFFS) and adjustment factors for less than ideal conditions.

$$FFS = BFFS - f_{LW} - f_{LC} - f_N - f_{ID} \qquad (23\text{-}1)$$

where

FFS = free-flow speed (mi/h),
BFFS = base free-flow speed, 70 mi/h (urban) or 75 mi/h (rural),
f_{LW} = adjustment for lane width (mi/h),
f_{LC} = adjustment for right-shoulder lateral clearance (mi/h),
f_N = adjustment for number of lanes (mi/h), and
f_{ID} = adjustment for interchange density (mi/h).

The ideal conditions for a basic freeway segment are 12-foot minimum lane widths, 6-foot minimum right-shoulder lateral clearance, 2-foot minimum median lateral clearance, only passenger cars in traffic stream, five or more lanes in each direction for urban freeways, two or more miles between interchanges, and a driver population made up primarily of regular commuters. Adjustment factors are used to correct for deviations from these "ideal" conditions. The adjustment factors for lane width (f_{LW}), right-shoulder lateral clearance (f_{LC}), number of lanes (f_N), and interchange density (f_{ID}), can be found in Tables A2, A3, A4, and A5, respectively.

Lane Width (ft)	Reduction in Free-Flow Speed, f_{LW} (mi/h)
12	0.0
11	1.9
10	6.6

Table A2. Adjustments for Lane Width (HCM Exhibit 23-4)

	Reduction in Free-Flow Speed, F_{LC} (mi/h)			
	Lanes in One Direction			
Right-Shoulder Lateral Clearance (ft)	2	3	4	≥ 5
≥ 6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	3.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

Table A3. Adjustments for Right-Shoulder Lateral Clearance (HCM Exhibit 23-5)

Number of Lanes (One Direction)	Reduction in Free-Flow Speed, f_N (mi/h)
≥ 5	0.0
4	1.5
3	3.0
2	4.5
Note: For all rural freeway segments, f_N is 0.0.	

Table A4. Adjustments for Number of Lanes (HCM Exhibit 23-6)

Interchanges per Mile	Reduction in Free-Flow Speed, f_{ID} (mi/h)
0.50	0.0
0.75	1.3
1.00	2.5
1.25	3.7
1.5	5.0
1.75	6.3
2.00	7.5

Table A5. Adjustments for Interchange Density (HCM Exhibit 23-7)

Since most HCM procedures make use of a peak 15-min flow rate, adjustments must be made to hourly flows to account for variations within the peak hourly flow, heavy vehicles, number of lanes, and any unfamiliar drivers in the driver population. HCM Equation 23-2 is used to calculate the 15-minute passenger-car equivalent flow rate.

$$v_p = \frac{V}{PHF * N * f_{HV} * f_p} \qquad (23\text{-}2)$$

where

v_p = 15-min passenger-car equivalent flow rate (pc/h/ln),
V = hourly volume (vehicles/h),
PHF = peak-hour factor,
N = number of lanes,
f_{HV} = heavy-vehicle adjustment factor, and
f_p = driver population factor.

The peak-hour factor (PHF) accounts for the variation of traffic flow within a one-hour period, since flow during the peak 15-minutes can be substantially higher than that experienced during the remainder of the peak hour. If the peak 15-minute flow *rate* is measured directly, use a PHF of 1.0. The driver population factor, f_p, accounts for any general unfamiliarity of drivers with the facility. This factor is generally assumed to be 1.0 unless there is evidence to the contrary. The heavy-vehicle adjustment factor converts the mix of all vehicle types into passenger cars only. This adjustment is necessary because heavy vehicles require more space than passenger cars do. This factor can be found using HCM Equation 23-3.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \qquad (23\text{-}3)$$

where

f_{HV} = heavy-vehicle adjustment factor,
E_T = passenger-car equivalent for trucks/buses,
E_R = passenger-car equivalent for recreational vehicles (RVs),
P_T = proportion of trucks/buses in the traffic stream, and
P_R = proportion of RVs in the traffic stream.

The passenger-car equivalent (PCE) values for trucks, buses, and RVs represent the number of passenger cars that would occupy the same amount of the freeway capacity as one truck, bus, or RV. This factor accounts not only for the increased length of a heavy-vehicle but also decreased heavy-vehicle performance due to the freeway grades. When there is no grade 3 percent or greater for longer than 0.25 miles or no grade of 2-3 percent for greater than 0.5 miles, Table A6 can be used to find the PCE. Otherwise, a specific grade analysis must be performed.

	Type of Terrain		
Factor	**Level**	**Rolling**	**Mountainous**
ET (trucks and buses)	1.5	2.5	4.5
ER (RVs)	1.2	2.0	4.0

Table A6. Passenger-Car Equivalents on Extended Freeway Segments (HCM Exhibit 23-8)

When finding the PCE using the extended freeway segment analysis in Table A6, the terrain must be classified as level, rolling, or mountainous. Level terrain is comprised of short grades no greater than 2 percent, which allow heavy vehicles to travel at the same speed as passenger cars. Rolling terrain causes heavy vehicles to operate at slower speeds than passenger cars but without having to resort to crawling speed. Finally, mountainous terrain causes heavy vehicles to operate at a very low rate of movement (crawl speed). A truck's crawl speed is the maximum speed that the truck can sustain on an extended grade. Eventually, if any grade is long enough a truck will reach its crawl speed for that grade.

For specific grade analysis, the percent of grade, length of grade, and proportion of heavy vehicles must be considered. Table A7 and A8 can be used to evaluate upgrade segments for trucks and RVs, respectively. For downgrades, if trucks do not have to shift into a low gear, the segment may be treated as if it were level terrain; otherwise, Table A9 can be used. For RVs, all downgrades may be treated as level terrain. For composite grades, the average grade can be used if all subsections are less steep than 4 percent or the total length of the composite grade is less than 4,000 ft. Otherwise, truck performance curves must be used to find the equivalent single grade for analysis.

Upgrade (%)	Length (mi)	E_T								
		Percentage of Trucks and Buses								
		2	4	5	6	8	10	15	20	25
< 2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
≥ 2-3	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.50-0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.75-1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 1.00-1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
> 3-4	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.50-0.75	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	> 0.75-1.00	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 1.00-1.50	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	> 1.50	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
> 4-5	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.50-0.75	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.75-1.00	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.00	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
> 5-6	0.00-0.25	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.30	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.30-0.50	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.50-0.75	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	> 0.75-1.00	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	> 1.00	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
> 6	0.00-0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 0.25-0.30	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	> 0.30-0.50	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	> 0.50-0.75	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	> 0.75-1.00	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	> 1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

Table A7. Passenger-Car Equivalents for Trucks and Buses on Upgrades(HCM Exhibit 23-9)

		E_R								
Upgrade	Length	Percentage of RVs								
(%)	(mi)	2	4	5	6	8	10	15	20	25
≤ 2	All	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
> 2-3	0.00-0.50	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.50	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
	0.00-0.25	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
> 3-4	> 0.25-0.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
	0.00-0.25	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
> 4-5	> 0.25-0.50	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.50	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
	0.00-0.25	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
> 5	> 0.25-0.50	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	> 0.50	6.0	4.5	4.0	4.0	3.5	3.0	3.0	2.5	2.0

Table A8. Passenger-Car Equivalents for RVs on Upgrades (HCM Exhibit 23-10)

		E_T			
Downgrade	Length	Percentage of Trucks			
(%)	(mi)	5	10	15	20
< 4	All	1.5	1.5	1.5	1.5
4-5	≤ 4	1.5	1.5	1.5	1.5
4-5	> 4	2.0	2.0	2.0	1.5
> 5-6	≤ 4	1.5	1.5	1.5	1.5
> 5-6	> 4	5.5	4.0	4.0	3.0
> 6	≤ 4	1.5	1.5	1.5	1.5
> 6	> 4	7.5	6.0	5.5	4.5

Table A9. Passenger-Car Equivalents for Trucks and Buses on Downgrades (HCM Exhibit 23-11)

Multilane Highways

Figure A2 graphically depicts the methodology for estimating LOS for a multilane highway. It is very similar to that used for freeways. A notable difference consists of the factors used to adjust free flow speed. For multilane highways, median type and access points are critical factors, and replace the number of lanes and interchange density adjustments used for freeways.

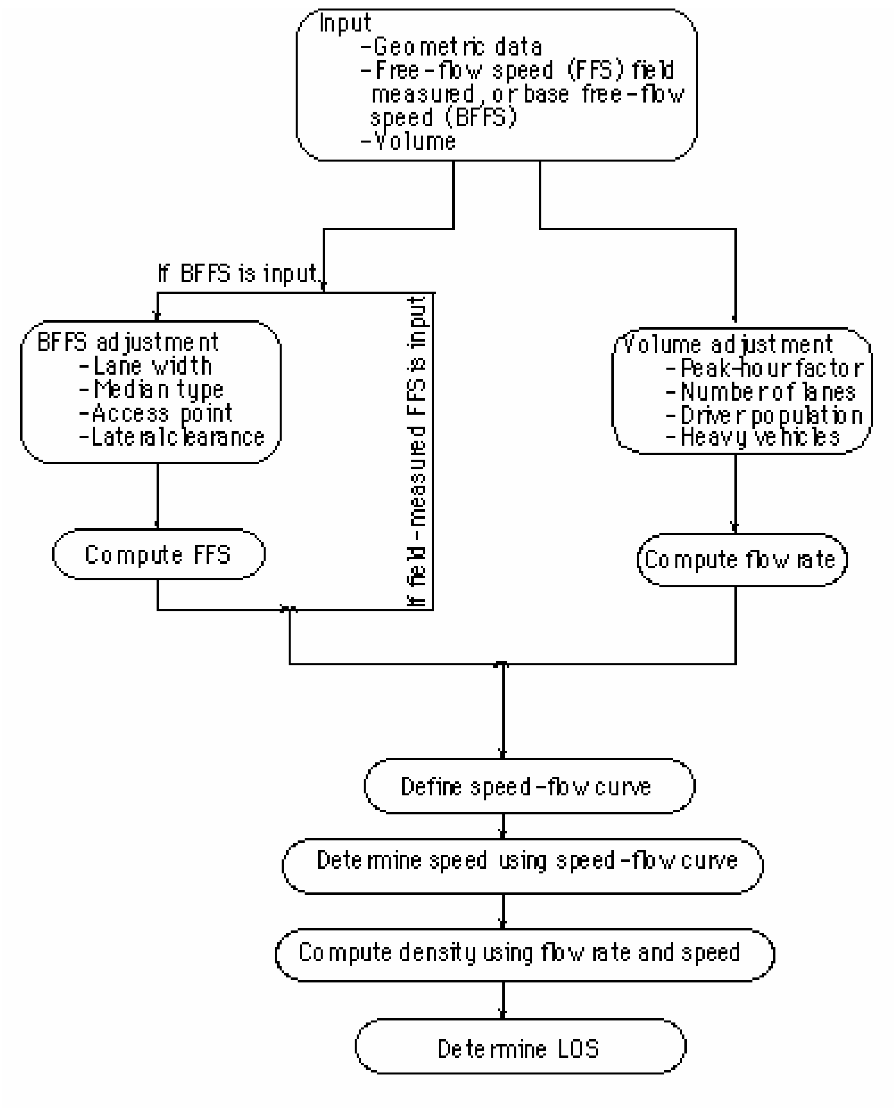


Figure A2. Multilane Highway Methodology (HCM Exhibit 21-1)

LOS criteria for multilane highways is given in Table A10 in terms of such operating conditions as FFS, density, average speed, volume to capacity ratio, and maximum service flow rate. The same density thresholds are used for both multilane highways and freeways, as shown graphically in Figure 2 in the summary of Multilane Highways in the Literature Review.

		LOS				
Free-Flow Speed	Criteria	A	B	C	D	E
60 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	40
	Average speed (mi/h)	60.0	60.0	59.4	56.7	55.0
	Maximum volume to capacity ratio (v/c)	0.30	0.49	0.70	0.90	1.00
	Maximum service flow rate (pc/h/ln)	660	1080	1550	1980	2200
55 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	41
	Average speed (mi/h)	55.0	55.0	54.9	52.9	51.2
	Maximum v/c	0.29	0.47	0.68	0.88	1.00
	Maximum service flow rate (pc/h/ln)	600	990	1430	1850	2100
50 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	43
	Average speed (mi/h)	50.0	50.0	50.0	48.9	47.5
	Maximum v/c	0.28	0.45	0.65	0.86	1.00
	Maximum service flow rate (pc/h/ln)	550	900	1300	1710	2000
45 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	45
	Average speed (mi/h)	45.0	45.0	45.0	44.4	42.2
	Maximum v/c	0.26	0.43	0.62	0.82	1.00
	Maximum service flow rate (pc/h/ln)	490	810	1170	1550	1900

Note:
The exact mathematical relationship between density and volume to capacity ratio (v/c) has not always been maintained at LOS boundaries because of the use of rounded values. Density is the primary determinant of LOS. LOS F is characterized by highly unstable and variable traffic flow. Prediction of accurate flow rate, density, and speed at LOS F is difficult.

Table A10. LOS Criteria for Multilane Highways (HCM Exhibit 21-2)

As with freeways, a free-flow speed (FFS) and operating conditions are used to determine LOS. The best way to find FFS is to measure it in the field under low to moderate flows. When field measurements are not available, HCM Equation 21-1 can be used to approximate FFS using an assumed Base Free Flow Speed (BFFS) and adjustment factors for less than ideal conditions. Base conditions for multilane highways are 12-foot minimum lane widths, 12-foot minimum total lateral clearance, passenger cars only, no direct access points, and a divided highway.

$$FFS = BFFS - f_{LW} - f_{LC} - f_M - f_A \qquad (21\text{-}1)$$

where

- FFS = free-flow speed (mi/h),
- BFFS = base free-flow speed, 60 mi/h,
- f_{LW} = adjustment for lane width (mi/h),
- f_{LC} = adjustment for lateral clearance (mi/h),
- f_M = adjustment for median type (mi/h), and
- f_{AP} = adjustment for access points (mi/h).

The adjustment factors for lane width (f_{LW}), lateral clearance (f_{LC}), median type (f_M), and number of access points (f_{AP}), can be found in Tables A11, A12, A13, and A14, respectively. Unlike freeways, lateral clearances on both the right and left sides of the highway affect FFS; therefore, the lateral clearance referred to in Table 19 is the total lateral clearance for both sides. See Note *a* below the exhibit for further clarification.

Lane Width (ft)	Reduction in FFS (mi/h)
12	0.0
11	1.9
10	6.6

Table A11. Adjustment for Lane Width (HCM Exhibit 21-4)

Four-Lane Highways		Six-Lane Highways	
Total Lateral Clearance[a]	Reduction in FFS (mi/h)	Total Lateral Clearance[a] (ft)	Reduction in FFS (mi/h)
12	0.0	12	0.0
10	0.4	10	0.4
8	0.9	8	0.9
6	1.3	6	1.3
4	1.8	4	1.7
2	3.6	2	2.8
0	5.4	0	3.9
Note: [a] Total lateral clearance is the sum of the lateral clearances of the median (if greater than 6 ft, use 6 ft) and shoulder (if greater than 6 ft, use 6 ft). Therefore, for purposes of analysis, total lateral clearance cannot exceed 12 ft.			

Table A12. Adjustment for Lateral Clearance (HCM Exhibit 21-5)

Median Type	Reduction in FFS (mi/h)
Undivided Highways	1.6
Divided Highways (including TWLTLs)	0.0

Table A13. Adjustment for Median Type (HCM Exhibit 21-6)

Access Points/Mile	Reduction in FFS (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
≥ 40	10.0

Table A14. Access-Point Density Adjustment (HCM Exhibit 21-7)

Since most HCM procedures make use of a peak 15-min flow rate, adjustments must be made to hourly flows to account for variations within the peak hourly flow, heavy vehicles, number of lanes, and unfamiliar drivers. HCM Equation 21-3 is used to calculate the 15-minute passenger-car equivalent flow rate.

$$v_p = \frac{V}{PHF * N * f_{HV} * f_p} \qquad (21\text{-}3)$$

where

v_p = 15-min passenger-car equivalent flow rate (pc/h/ln),
V = hourly volume (veh/h),
PHF = peak-hour factor,
N = number of lanes,
f_{HV} = heavy-vehicle adjustment factor and
f_p = driver population factor.

The peak-hour factor (PHF) accounts for the variation of traffic flow within a one-hour period, since flow during the peak 15-minutes is typically not sustained throughout the entire hour. If the peak 15-min flow *rate* is measured directly, use a PHF of 1.0.

The driver population factor, f_p, accounts for any unfamiliarity of drivers with the facility. This factor is generally assumed to be 1.0 unless there is evidence to the contrary.

The heavy-vehicle adjustment factor converts the mix of all vehicle types into passenger cars only. This adjustment is necessary because heavy vehicles require more space than do passenger cars. This factor can be found using HCM Equation 21-4.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \qquad (21\text{-}4)$$

where
- f_{HV} = heavy-vehicle adjustment factor,
- E_T = passenger-car equivalent for trucks/buses,
- E_R = passenger-car equivalent for recreational vehicles (RVs),
- P_T = proportion of trucks/buses in the traffic stream, and
- P_R = proportion of RVs in the traffic stream.

Passenger-car equivalents (PCEs) for trucks, buses, and RVs exist for two different terrain conditions. If a segment has no grade greater than 3 percent for more than 0.5 miles and no grade 3 percent or less that is longer than 1 mile, the segment can be analyzed as an extended general highway segment using Table A15. The terrain for the segment is then classified as level, rolling, or mountainous.

	Type of Terrain		
Factor	**Level**	**Rolling**	**Mountainous**
ET (trucks and buses)	1.5	2.5	4.5
ER (RVs)	1.2	2.0	4.0

Table A15. Type of Terrain (HCM Exhibit 21-8)

Any specific grade of 3 percent or less for longer than 1 mile or greater than 3 percent for more than 0.5 miles should be analyzed as a separate segment. For uniform upgrades, Table A16 is used for trucks and buses and Table A17 is used for RVs. For downgrades less than 4 percent and for steeper downgrades less than 2 miles long; trucks and buses use the PCEs for level terrain. Otherwise, use Table A18. For all cases of RVs on downgrades use PCEs for level terrain.

Upgrade (%)	Length (mi)	E_T								
		Percentage of Trucks and Buses								
		2	4	5	6	8	10	15	20	25
<2	All	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
≥ 2-3	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.50-0.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.75-1.00	2.0	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
	> 1.00-1.50	2.5	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 1.50	3.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
> 3-4	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.50-0.75	2.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	> 0.75-1.00	3.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 1.00-1.50	3.5	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
	> 1.50	4.0	3.5	3.0	3.0	3.0	3.0	2.5	2.5	2.5
> 4-5	0.00-0.25	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.50-0.75	3.5	3.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.75-1.00	4.0	3.5	3.5	3.5	3.0	3.0	3.0	3.0	3.0
	> 1.00	5.0	4.0	4.0	4.0	3.5	3.5	3.0	3.0	3.0
> 5-6	0.00-0.25	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	> 0.25-0.30	4.0	3.0	2.5	2.5	2.0	2.0	2.0	2.0	2.0
	> 0.30-0.50	4.5	4.0	3.5	3.0	2.5	2.5	2.5	2.5	2.5
	> 0.50-0.75	5.0	4.5	4.0	3.5	3.0	3.0	3.0	3.0	3.0
	> 0.75-1.00	5.5	5.0	4.5	4.0	3.0	3.0	3.0	3.0	3.0
	> 1.00	6.0	5.0	5.0	4.5	3.5	3.5	3.5	3.5	3.5
> 6	0.00-0.25	4.0	3.0	2.5	2.5	2.5	2.5	2.0	2.0	2.0
	> 0.25-0.30	4.5	4.0	3.5	3.5	3.5	3.0	2.5	2.5	2.5
	> 0.30-0.50	5.0	4.5	4.0	4.0	3.5	3.0	2.5	2.5	2.5
	> 0.50-0.75	5.5	5.0	4.5	4.5	4.0	3.5	3.0	3.0	3.0
	> 0.75-1.00	6.0	5.5	5.0	5.0	4.5	4.0	3.5	3.5	3.5
	> 1.00	7.0	6.0	5.5	5.5	5.0	4.5	4.0	4.0	4.0

Table A16. Passenger Car Equivalents for Trucks and Buses on Uniform Upgrades (HCM Exhibit 21-9)

		E_R								
Grade	Length	Percentage of RVs								
(%)	(mi)	2	4	5	6	8	10	15	20	25
≤2	All	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
> 2-3	0.00-0.50	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
	> 0.50	3.0	1.5	1.5	1.5	1.5	1.5	1.2	1.2	1.2
	0.00-0.25	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
> 3-4	> 0.25-0.50	2.5	2.5	2.0	2.0	2.0	2.0	1.5	1.5	1.5
	> 0.50	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5	1.5
	0.00-0.25	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
> 4-5	> 0.25-0.50	4.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
	> 0.50	4.5	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0
	0.00-0.25	4.0	3.0	2.5	2.5	2.5	2.0	2.0	2.0	1.5
> 5	> 0.25-0.50	6.0	4.0	4.0	3.5	3.0	3.0	2.5	2.5	2.0
	> 0.50	6.0	4.5	4.0	4.0	3.5	3.0	3.0	2.5	2.0

Table A17. Passenger Car Equivalents for RVs on Uniform Upgrades (HCM Exhibit 21-10)

		E_T			
Downgrade	Length	Percentage of Trucks			
(%)	(mi)	5	10	15	20
< 4	All	1.5	1.5	1.5	1.5
4-5	≤ 4	1.5	1.5	1.5	1.5
4-5	> 4	2.0	2.0	2.0	1.5
> 5-6	≤ 4	1.5	1.5	1.5	1.5
> 5-6	> 4	5.5	4.0	4.0	3.0
> 6	≤ 4	1.5	1.5	1.5	1.5
> 6	> 4	7.5	6.0	5.5	4.5

Table A18. Passenger Car Equivalents for Trucks on Downgrades (HCM Exhibit 21-11)

Urban Streets (Arterials)

Figure A3 graphically depicts the methodology for determining LOS on an urban street.

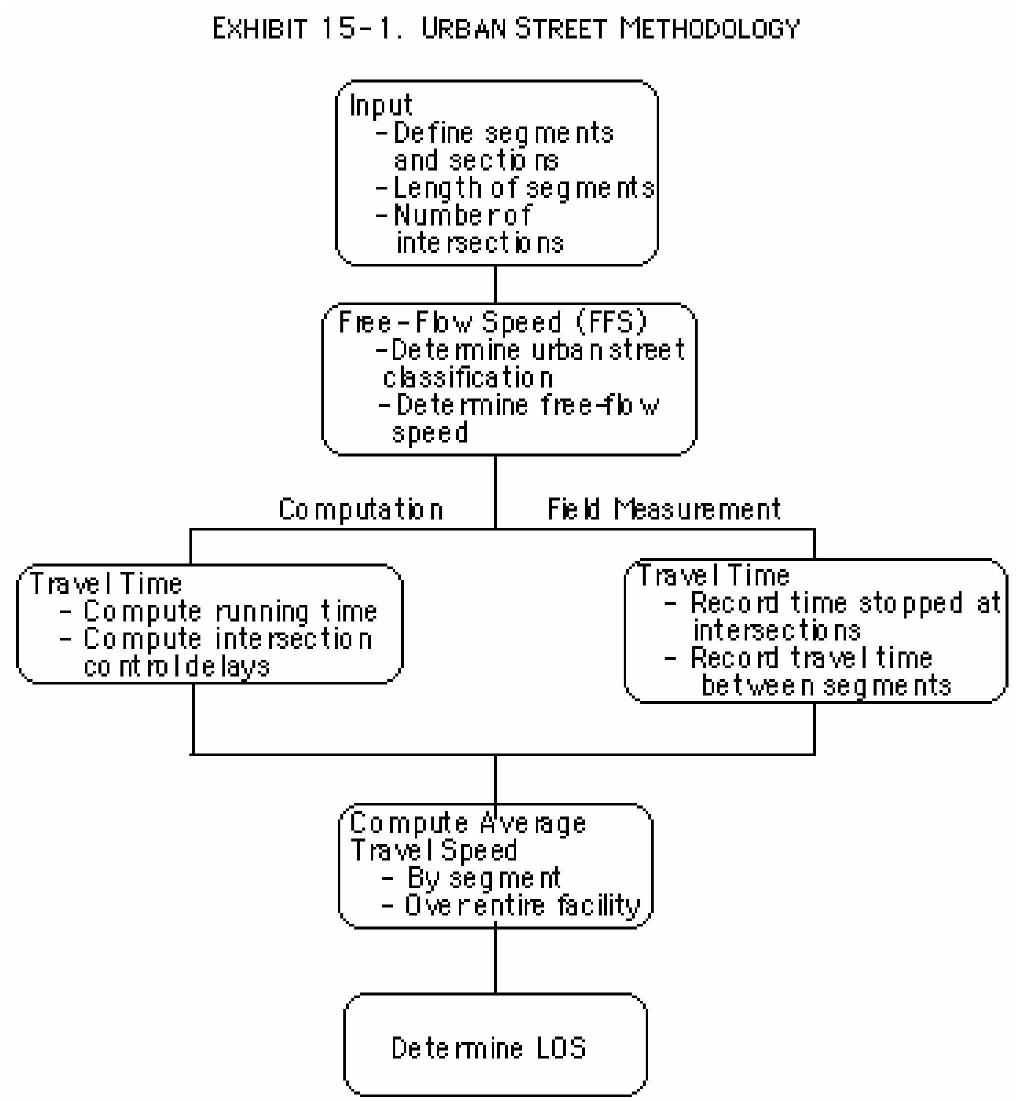


Figure A3. Urban Street (Arterial) Methodology (HCM Exhibit 15-1)

LOS is determined using Table A19 once the urban street class, range of FFS, typical FFS, and average travel speed are known.

Urban Street Class	I	II	III	IV
Range of free-flow speeds (FFS)	55 to 45 mi/h	45 to 35 mi/h	35 to 30 mi/h	35 to 25 mi/h
Typical FFS	50 mi/h	40 mi/h	35 mi/h	30 mi/h
LOS	Average Travel Speed (mi/h)			
A	> 42	> 35	>30	>25
B	> 34 – 42	> 28 – 35	>24 – 30	> 19 – 25
C	> 27 – 34	>22 – 28	> 18 -24	> 13 – 19
D	> 21 – 27	> 17 – 22	> 14 – 18	> 9 – 13
E	> 16 – 21	> 13 – 17	>10 – 14	> 7 – 9
F	≤ 16	≤ 13	≤ 10	≤ 7

Table A19. Urban Street LOS by Class (HCM Exhibit 15-2)

The first step in urban street analysis is determining the street's class. Direct measurement of FFS is the best method for classification, otherwise an assessment of the street's functional and design categories can be used. Identification of functional category and design category can be performed using Table A20.

	Functional Category	
Design Category	Principal Arterial	Minor Arterial
High-Speed	I	N/A
Suburban	II	II
Intermediate	II	III or IV
Urban	III or IV	IV

Table A20. Urban Street Class Based on Functional and Design Categories (HCM Exhibit 10-3)

At signalized intersections, the two main components of total travel time are running time and control delay. Running time is the portion of the travel time during which a vehicle is in motion. Control delay is the component of delay that results when a control signal causes a lane group to reduce speed or to stop. It is measured by a comparison with the uncontrolled condition. Street classification, segment length, and FFS are needed to calculate running time using Table A21.

Urban Street Class	I			II			III		IV		
FFS (mi/h)	55[a]	50[a]	45[a]	45[a]	40[a]	35[a]	35[a]	30[a]	35[a]	30[a]	25[a]
Average Segment Length (mi)	Running Time per Mile (s/mi)										
0.05	b	b	b	b	b	b	-	-	-	227	265
0.10	b	b	b	b	b	b	145	155	165	180	220
0.15	b	b	b	b	b	b	135	141	140	150	180
0.20	b	b	b	109	115	125	128	134	130	140	165
0.25	97	100	104	104	110	119	120	127	122	132	153
0.30	92	95	99	99	102	110	d	d	d	d	d
0.40	82	86	94	94	96	105	d	d	d	d	d
0.50	73	78	88	88	93	103	d	d	d	d	d
1.00	65[c]	72[c]	80[c]	80[c]	90[c]	103[c]	d	d	d	d	d

Notes:

a. It is best to have an estimate of FFS. If there is none, use the table above, assuming the following default values:

For Class	FFS (mi/h)
I	50
II	40
III	35
IV	30

b. If a Class I or II urban street has a segment length less than 0.20 mi (a) reevaluate the class and (b) if it remains a distinct segment, use the values for 0.20 mi.

c. For long segment lengths on Class I or II urban streets (1 mi or longer), FFS may be used to compute running time per mile. These times are shown in the entries for a 1.0-mi segment.

d. Likewise, Class III or IV urban streets with segment lengths greater than 0.25 mi should first be reevaluated (i.e., the classification should be confirmed). If necessary, the values above 0.25 mi can be extrapolated.

Although this table does not show it, segment running time depends on traffic flow rates; however, the dependence of intersection delay on traffic flow rate is greater and dominates in the computation of travel speed.

Table A21. Segment Running Time per Mile (HCM Exhibit 15-3)

The control delay used in urban street analysis is that for the through movement. HCM Equations 15-1, 15-2, and 15-3 are used to compute control delay, uniform delay, and incremental delay, respectively. Control delay is a function of uniform delay (d_1), incremental delay (d_2), and initial queue delay (d_3). As noted earlier, control delay is defined as the component of delay that results when a control signal causes a lane group to reduce speed or to stop; it is measured by comparison with the uncontrolled condition. Uniform delay, d_1, is based on the assumption of uniform arrivals. This is a reasonable assumption for how vehicles are going to arrive at an isolated intersection at any given time. Incremental delay, d_2, accounts for additional deal from non-uniform arrivals and temporary random delays as well as delays caused by sustained periods of over saturation. The third term, initial queue delay (d_3), refers to the delay due to a residual queue identified in a previous analysis period and persisting at the start of the current analysis period. This delay results from the additional time required to clear the initial queue. Equations 15-2 and 15-3 are shown below and are used to calculate uniform and incremental delay, or d_1 and d_2, respectively.

$$d = d_1(PF) + d_2 + d_3 \quad (15\text{-}1)$$

$$d_1 = \frac{0.5C\left(1-\frac{g}{C}\right)^2}{1-\left[\min(1,X)\frac{g}{C}\right]} \quad (15\text{-}2)$$

$$d_2 = 900T\left[(X-1)+\sqrt{(X-1)^2+\frac{8kIX}{cT}}\right] \quad (15\text{-}3)$$

where

- d = control delay (s/veh),
- d_1 = uniform delay (s/veh),
- d_2 = incremental delay (s/veh),
- d_3 = initial queue delay, see Chapter 16 of HCM 2000 (s/veh),
- PF = progression adjustment factor (Table 49),
- X = volume to capacity (v/c) ratio for the lane group (also termed degree of saturation),
- C = cycle length (s),
- c = capacity of lane group (veh/h),
- g = effective green time for lane group,
- T = duration of analysis period (h),
- k = incremental delay adjustment for the actuated control, and
- I = incremental delay adjustment for the filtering or metering.

The arrival type for an urban street is a parameter describing the quality of the street's progression, for each lane group. There are six arrival types, Arrival Type 1 through 6. Table A22 summarizes for each arrival type the range of Platoon Ratio (calculated using HCM Equation 15-4), the default value for the Platoon Ratio, and the progression quality. The proportion of all vehicles arriving during green, needed for HCM Equation 15-4, can be estimated or observed in the field.

Arrival Type	Range of Platoon Ratio (R_p)	Default Value (R_p)	Progression Quality
1	≤ 0.50	0.333	Very poor
2	> 0.50-0.85	0.667	Unfavorable
3	> 0.85-1.15	1.000	Random Arrivals
4	> 1.15-1.50	1.333	Favorable
5	> 1.50-2.00	1.667	Highly favorable
6	> 2.00	2.0000	Exceptional

Table A22. Relationship between Arrival Type and Platoon Ratio (R_p) (HCM Exhibit 15-4)

$$R_p = P(C/g) \qquad (15\text{-}4)$$

where
- Rp = platoon ratio,
- P = proportion of all vehicles arriving during green,
- C = cycle length (s), and
- g = effective green time for movement (s).

The progression adjustment factor, PF, takes into account the affect of signal coordination and the resulting progression on uniform delay. PF can be found using HCM Equation 15-5 or Table A23.

$$PF = \frac{(1-P)\,f_{PA}}{\left(1-\frac{g}{C}\right)} \qquad (15\text{-}5)$$

where
- PF = progression adjustment factor,
- P = proportion of all vehicles arriving during green,
- g/C = effective green-time ratio, and
- f_{PA} = supplemental adjustment factor for platoon arrival during the green.

	Arrival Type (AT)					
Green Ratio(g/C)	AT 1	AT 2	AT 3	AT 4	AT 5	AT 6
0.20	1.167	1.007	1.000	1.000	0.833	0.750
0.30	1.286	1.063	1.000	0.986	0.714	0.571
0.40	1.445	1.136	1.000	0.895	0.555	0.333
0.50	1.667	1.240	1.000	0.767	0.333	0.000
0.60	2.001	1.395	1.000	0.576	0.000	0.000
0.70	2.556	1.653	1.000	0.256	0.000	0.000
f_{PA}	1.00	0.93	1.00	1.15	1.00	1.00
Default, R_p	0.333	0.667	1.000	1.333	1.667	2.000

Table A23. Progression Adjustment Factors for Uniform Delay Calculation (HCM Exhibit 15-5)

Note that when Table A23 is used to determine the progression adjustment factor, the default values for P and f_{PA} for each arrival type are used. When estimating these parameters for future coordination, Arrival Type 4 should be assumed for coordinated lane groups and Arrival Type 3 should be assumed for uncoordinated lane groups.

HCM Equation 15-6 is used to determine travel speed for each segment and for an entire section.

$$S_A = \frac{3600L}{T_R + d} \qquad (15\text{-}6)$$

where

S_A = average travel speed of through vehicles in the segment (mi/h),
L = segment length (mi),
T_R = total of running time on all segments in defined section (s), and
d = control delay for through movements at the signalized intersection (s).

Two-Lane Highways

The basic methodology for two-lane highways is given in Figure A4. The two sides of the methodology reflect the separate steps required to determine values for two distinct MOEs. Both components of the two-lane methodology involve *distinct* demand adjustments and subsequent, *distinct* flow rate computations.

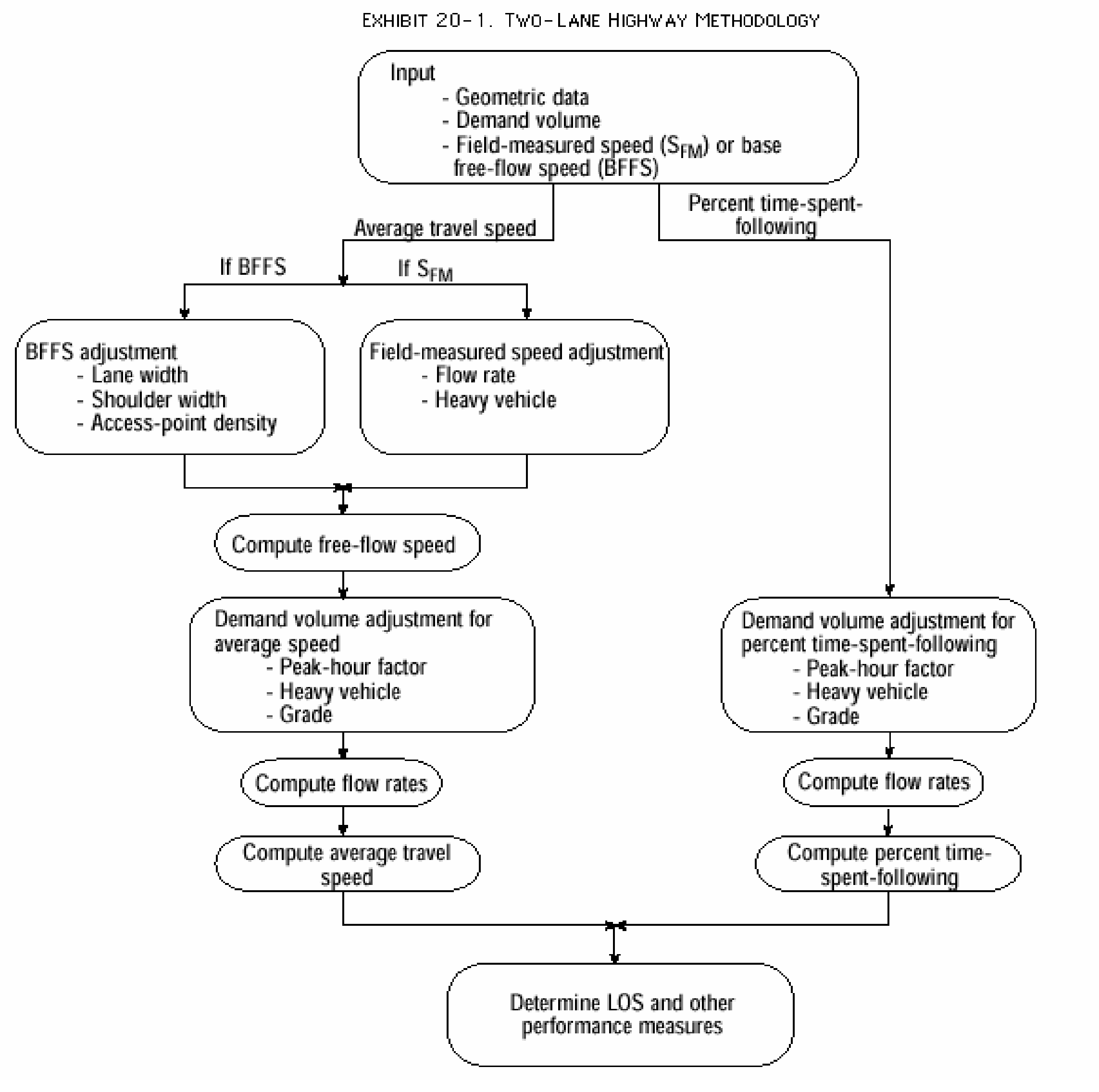


Figure A4. Two-Lane Highway Methodology (HCM Exhibit 20-1)

There are two classifications of two-lane highways based on the perceived purpose of the facility by the highway user. Class I consists of those facilities where *mobility* is the primary function. On these highways LOS is defined in terms of both average travel speed and percent time-spent-following. Class II is comprised of highways for which *accessibility* is more important than mobility. For these highways, only percent time-spent-following is considered when determining LOS. Additionally, users of Class II highways tolerate a higher percent time-spent-following since these facilities tend to service shorter trips and different purposes than Class I highways.

Two-lane highways can be analyzed as either two-way segments or directional segments. In general, segments that are at least two miles long and have either level or rolling terrain can be analyzed as two-way segments and segments with mountainous terrain are analyzed as specific upgrade or downgrade directional segments. Of course, "directional" segments still have two-way traffic.

Two-Way Segments

Free flow speed (FFS) for a two-lane highway is best determined by direct measurement in the field when two-way flows are 200 pc/h or less. If the FFS is measured when two-way flows are more than 200 pc/h, the FFS can be calculated using Equation 20-1.

$$FFS = S_{FM} + 0.00776 \frac{V_f}{f_{HV}} \qquad (20\text{-}1)$$

where
- FFS = estimated free-flow speed (mi/h),
- S_{FM} = mean speed of traffic measured in the field (mi/h),
- V_f = observed flow rate for the period when field data were obtained (veh/h), and
- f_{HV} = heavy-vehicle adjustment factor, determined as shown in Equation 20-4).

If no field data is available, FFS can be estimated using an assumed BFFS and adjustments for lane and shoulder width and access points as given in HCM Equation 20-2. No guidance is provided for choosing a BFFS due to the wide variance in values**.** Estimates should be based on speed data, knowledge of local operating conditions, design speed, and posted speed limit.

$$FFS = BFFS - f_{LS} - f_A \qquad (20\text{-}2)$$

where
- FFS = estimated FFS (mi/h),
- BFFS = base FFS (mi/h),
- f_{LS} = adjustment for lane width and shoulder width, from Table A24, and
- f_A = adjustment for access points, from Table A25.

Base conditions for a two-lane highway are 12-foot lanes, 6-foot shoulders, and zero access points. Tables A24 and A25 give reduction factors for deviations from these base conditions.

	Reduction in FFS (mi/h)			
	Shoulder Width (ft)			
Lane Width (ft)	≥ 0 < 2	≥ 2 < 4	≥ 4 < 6	≥ 6
9 < 10	6.4	4.8	3.5	2.2
≥ 10 < 11	5.3	3.7	2.4	1.1
≥ 11 < 12	4.7	3.0	1.7	0.4
≥ 12	4.2	2.6	1.3	0.0

Table A24. Reduction in FFS(mi/h) with Varying Lane and Shoulder Widths (HCM Exhibit 20-5)

Access Points per Mile	Reduction in FFS (mi/h)
0	0.0
10	2.5
20	5.0
30	7.5
40	10.0

Table A25. Reduction in FFS (mi/h) with Varying Access Points (HCM Exhibit 20-6)

To determine demand flow rate, flow must be adjusted using the PHF, the grade adjustment factor, and the heavy-vehicle adjustment factor as shown in HCM Equation 20-3.

$$v_p = \frac{V}{PHF * f_G * f_{HV}} \qquad (20\text{-}3)$$

where

v_p = passenger-car equivalent flow rate for peak 15-min period (pc/h),
V = demand volume for the full peak hour (vehicles/h),
PHF = peak hour factor,
f_G = grade adjustment factor, and
f_{HV} = heavy-vehicle adjustment factor.

The grade adjustment factor accounts for affects of terrain on both average speeds and percent time-spent-following regardless of the existence of heavy vehicles. *Note – the same HCM Equation (20-3) is used to determine flow rates for both the average travel speed and percent time spent following methodologies. However the values of the adjustment factors input in the equation are different for each methodology.* Table A26 gives grade adjustments for speeds while Table A27 gives grade adjustments for percent time-spent-following.

Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
		Level	Rolling
0-600	0-300	1.00	0.71
> 600-1200	>300-600	1.00	0.93
> 1200	> 600	1.00	0.99

Table A26. Grade Adjustment Factor (f_G) to Determine Speeds on Two-Way and Directional Segments (HCM Exhibit 20-7)

Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain	
		Level	Rolling
0-600	0-300	1.00	0.77
> 600-1200	>300-600	1.00	0.94
> 1200	> 600	1.00	1.00

Table A27. Grade Adjustment Factor (f_G) to Determine Percent Time-Spent-Following on Two-Way and Directional Segments (HCM Exhibit 20-8)

The heavy vehicle adjustment factor is calculated using HCM Equation 20-4. The passenger-car equivalents for this equation are found in Tables A28 and A29 for speeds and percent time-spent-following, respectively.

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \qquad (20\text{-}4)$$

where

f_{HV} = heavy-vehicle adjustment factor,
P_T = proportion of trucks in the traffic stream, expressed as a decimal,
P_R = proportion of RVs in the traffic stream, expressed as a decimal,
E_T = passenger-car equivalent for trucks, obtained from Tables A26 and A27, and
E_R = passenger-car equivalent for RVs, obtained from Tables A28 and A29.

Vehicle Type	Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain: Level	Type of Terrain: Rolling
Trucks, E_T	0-600 > 600-1200 > 1200	0-300 >300-600 > 600	1.7 1.2 1.1	2.5 1.9 1.5
RVs, E_R	0-600 > 600-1200 > 1200	0-300 >300-600 > 600	1.0 1.0 1.0	1.1 1.1 1.1

Table A28. Passenger-Car Equivalents for Trucks and RVs to Determine Speeds on Two-Way and Directional Segments (HCM Exhibit 20-9)

Vehicle Type	Range of Two-Way Flow Rates (pc/h)	Range of Directional Flow Rates (pc/h)	Type of Terrain: Level	Type of Terrain: Rolling
Trucks, E_T	0-600 > 600-1200 > 1200	0-300 >300-600 > 600	1.1 1.1 1.0	1.8 1.5 1.0
RVs, E_R	0-600 > 600-1200 > 1200	0-300 >300-600 > 600	1.0 1.0 1.0	1.0 1.0 1.0

Table A29. Passenger-Car Equivalents for Trucks and RVs to Determine Percent Time-Spent-Following on Two-Way and Directional Segments (HCM Exhibit 20-10)

In Tables A28 and A29, short grades of no more than 1 or 2 percent should be classified as level terrain, while rolling terrain includes grades of no more than 4 percent for short and medium lengths. Segments with grades of more than 4 percent for a substantial length should be analyzed using the specific grade procedure for directional segments.

Tables A26 through A29 require the use of flow rates in passenger cars per hour; however, this flow rate is not known until computation of HCM Equation 20-3. As a result, an iterative approach is required to find the factors in these exhibits.

The first measure of effectiveness, *average travel speed*, can be found using FFS, the demand flow rate, and an adjustment factor for the percentage of no-passing zones, as shown in HCM Equation 20-5. Table A30 can be used to find the adjustment factor for the percentage of no-passing zones.

$$ATS = FFS - 0.00776v_p - f_{np} \qquad (20\text{-}5)$$

where

ATS = average travel speed for both directions of travel combined (mi/h),
FFS = free flow speed (mi/h),
v_p = passenger-car equivalent flow rate for peak 15-min period (pc/h), and
f_{np} = adjustment for percentage of no-passing zones.

	Reduction in Average Travel Speed (mi/h)					
	No-Passing Zones (%)					
Two-Way Demand Flow Rate, v_p (pc/h)	0	20	40	60	80	100
0	0.0	0.0	0.0	0.0	0.0	0.0
200	0.0	0.6	1.4	2.4	2.6	3.5
400	0.0	1.7	2.7	3.5	3.9	4.5
600	0.0	1.6	2.4	3.0	3.4	3.9
800	0.0	1.4	1.9	2.4	2.7	3.0
1000	0.0	1.1	1.6	2.0	2.2	2.6
1200	0.0	0.8	1.2	1.6	1.9	2.1
1400	0.0	0.6	0.9	1.2	1.4	1.7
1600	0.0	0.6	0.8	1.1	1.3	1.5
1800	0.0	0.5	0.7	1.0	1.1	1.3
2000	0.0	0.5	0.6	0.9	1.0	1.1
2200	0.0	0.5	0.6	0.9	0.9	1.1
2400	0.0	0.5	0.6	0.8	0.9	1.1
2600	0.0	0.5	0.6	0.8	0.9	1.0
2800	0.0	0.5	0.6	0.7	0.8	0.9
3000	0.0	0.5	0.6	0.7	0.7	0.8
3200	0.0	0.5	0.6	0.6	0.6	0.7

Table A30. Adjustment (f_{np}) for Effect of No-Passing Zones on Average Travel Speed on Two-Way Segments (HCM Exhibit 20-11)

Similarly, *percent time-spent following* is found as shown in HCM Equation 20-6, which includes a base percent time-spent-following and a factor that accounts for the directional distribution of traffic and the percentage of no-passing zones. The base percent time-spent-following is found using HCM Equation 20-7, which incorporates the demand flow rate. The adjustment factor for the combined effect of directional distribution of traffic and the percentage of no-passing zones can be found in Table A31.

$$PTSF = BPTSF + f_{d/np} \qquad (20\text{-}6)$$

where

- PTSF = percent time-spent following,
- BPTSF = base percent time-spent-following for both directions of travel combined (use Equation 20-7), and
- $f_{d/np}$ = adjustment for the combined effect of the directional distribution of traffic and of the percentage of no-passing zones on percent time-spent following.

$$BPTSF = 100\left(1 - e^{-0.000879 v_p}\right) \qquad (20\text{-}7)$$

where

- BPTSF = base percent time-spent-following for both directions of travel combined, and
- v_p = 15-min passenger-car equivalent flow rate (pc/h/ln)

Two-way flow rate, v_p (pc/h)	Increase in percent time-spent-following (%)					
	No-passing zones (%)					
	0	20	40	60	80	100
	Directional split = 50/50					
≤ 200	9.0	29.2	43.4	49.4	51.0	52.6
400	16.2	41.0	54.2	61.6	63.8	65.8
600	15.8	38.2	47.8	53.2	55.2	56.8
800	15.8	33.8	40.4	44.0	44.8	46.6
1400	12.8	20.0	23.8	26.2	27.4	28.6
2000	10.0	13.6	15.8	17.4	18.2	18.8
2600	5.5	7.7	8.7	9.5	10.1	10.3
3200	3.3	4.7	5.1	5.5	5.7	6.1
	Directional split = 60/40					
≤ 200	11.0	30.6	41.0	51.2	52.3	53.5
400	14.6	36.1	44.8	53.4	55.0	56.3
600	14.8	36.9	44.0	51.1	52.8	54.6
800	13.6	28.2	33.4	38.6	39.9	41.3
1400	11.8	18.9	22.1	25.4	26.4	27.3
2000	9.1	13.5	15.6	16.0	16.8	17.3
2600	5.9	7.7	8.6	9.6	10.0	10.2
	Directional split = 70/30					
≤ 200	9.9	28.1	38.0	47.8	48.5	49.0
400	10.6	30.3	38.6	46.7	47.7	48.8
600	10.9	30.9	37.5	43.9	45.4	47.0
800	10.3	23.6	28.4	33.3	34.5	35.5
1400	8.0	14.6	17.7	20.8	21.6	22.3
2000	7.3	9.7	15.7	13.3	14.0	14.5
	Directional split = 80/20					
≤ 200	8.9	27.1	37.1	47.0	47.4	47.9
400	6.6	26.1	34.5	42.7	43.5	44.1
600	4.0	24.5	31.3	38.1	39.1	40.0
800	4.8	18.5	23.5	28.4	29.1	29.8
1400	3.5	10.3	13.3	16.3	16.9	32.2
2000	3.5	7.0	8.5	10.1	10.4	10.7
	Directional split = 90/10					
≤ 200	4.6	24.1	33.6	43.1	43.4	43.6
400	0.0	20.2	28.3	36.3	36.7	37.0
600	-3.1	16.8	23.5	30.1	30.6	31.1
800	-2.8	10.5	15.2	19.9	20.3	20.8
1400	-1.2	5.5	8.3	11.0	11.5	11.9

Table A31. Adjustment ($f_{d/np}$) for Combined Effect of Directional Distribution of Traffic and Percent Age of No=Passing Zones on Percent Time-Distribution of Traffic and Percentage of No=Passing Zones on Percent Time-Spent-Following on Two-Way Segments (HCM Exhibit 20-12)

To determine the LOS for a two-way segment, first compare the total demand flow rate to the two-way capacity of 3,200 pc/h and the demand flow rate for each direction to 1,700 pc/h. If any of the demand flow rates is greater than the corresponding capacity then the segment is oversaturated and the LOS is F. If the segment is not over capacity then determine LOS using Figure 3 for Class I facilities and Table 4 for Class II facilities.

Directional Segments

The methodology for directional segments is similar to that for two-way segments except that LOS and other performance measures are determined for one direction of travel at a time. Three types of directional segments are addressed. These types are extended directional segments, specific upgrades, and specific downgrades. Extended directional segments have level or rolling terrain and are at least 2.0 miles in length. Any grade of 3 or more percent for at least 0.6 miles must be addressed as a specific upgrade or downgrade segment. Mountainous terrain is treated as a series of upgrade and downgrade segments.

Directional methodology is not presented here in detail. The Research Project Steering Committee decided that this would not be needed except in rare situations within a planning model; therefore, we did not need program this feature. If a situation came up requiring the use of this methodology, the analyst would use the Highway Capacity Software to solve for the needed output.

APPENDIX B: SENSITIVITY ANALYSIS DETAILS

As noted in the report, a review of the 2000 HCM sensitivity of variables for each facility type was summarized. Using this as a starting point, our research group then concentrated efforts towards defining the sensitivity of each variable for three of the four facility types. Significant analysis of two-lane highways was available in the 2000 HCM.

Sensitivity was measured using volume (veh/hr) as the independent variable and the facility's MOE as the dependant variable. By changing one, sometimes two variables (keeping other variables constant) at different volumes, we were able to record the level of service (LOS) at that specific point. The LOS was then plotted at the associated volumes for each variable(s) in question. These graphs showed the range effect for each variable, and thus we could determine the sensitivity of the variable.

Once the graphs were created, a scale of sensitivity was needed to establish what variables and factors might need further data collected in order to determine respectable default values. This sensitivity scale was broken into three categories: low, medium, and high. The graph for a variable with low sensitivity would show that changes in the variable would result in little to no variation in the LOS when examined over a range of volumes. In other words, the LOS (measured on the y-axis) does not vary by more than plus or minus one LOS over the range of the variable. Therefore, a low sensitivity variable could be easily assumed/defaulted based on various characteristics in the surrounding area of the roadway facility and ***would not*** need any further data collection efforts.

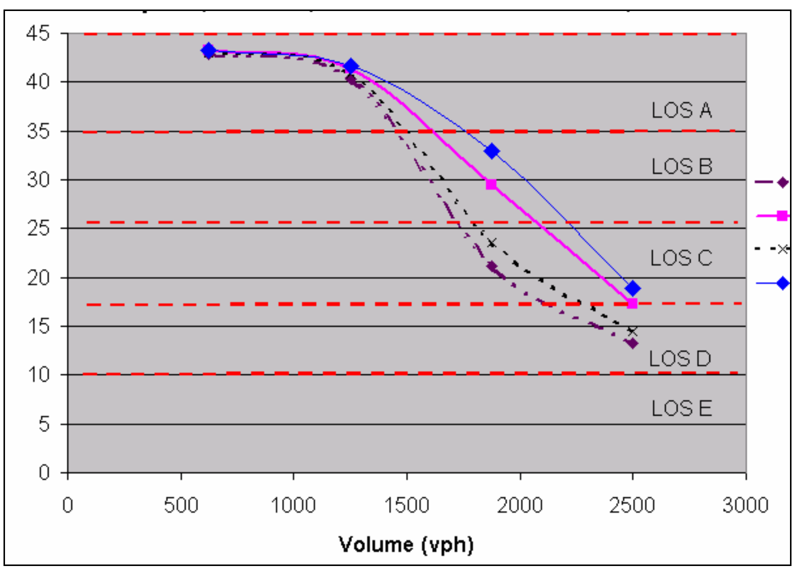


Figure B1. Example of a "Low" Sensitivity Variable

A graph showing medium sensitivity would have some variation in the LOS when examined over a range of volumes, but not over the majority of the spectrum. In other words, the LOS (measured on the y-axis) varies by more than plus or minus one LOS, but only along a portion of the graph (shown in the box). This type of variable would need to be considered as *possibly needing* more data to determine good default values.

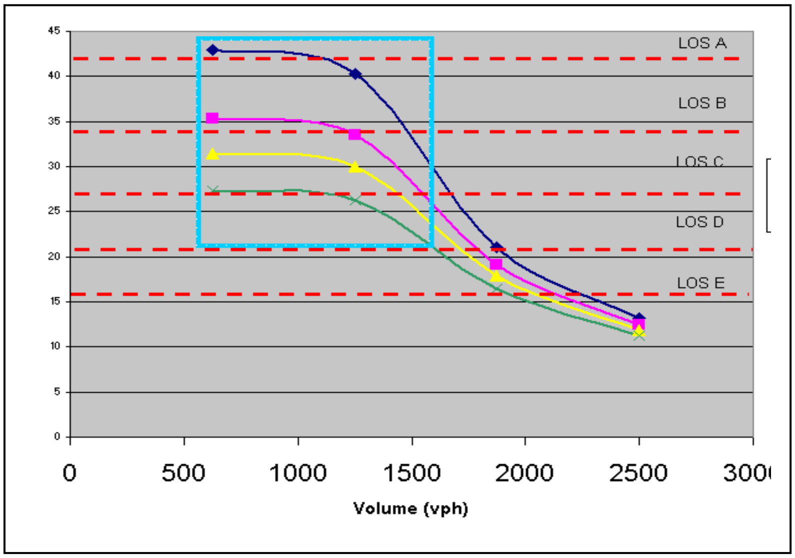


Figure B2. Example of a "Medium" Sensitivity Variable

A graph showing high sensitivity would have an extremely large variation in the LOS when examined over the range of volumes. This type of sensitivity is rare, and will cover all or most all the range of the graph (shown in the box). This type of variable would *definitely need* more data in order to determine default values for this type of roadway facility.

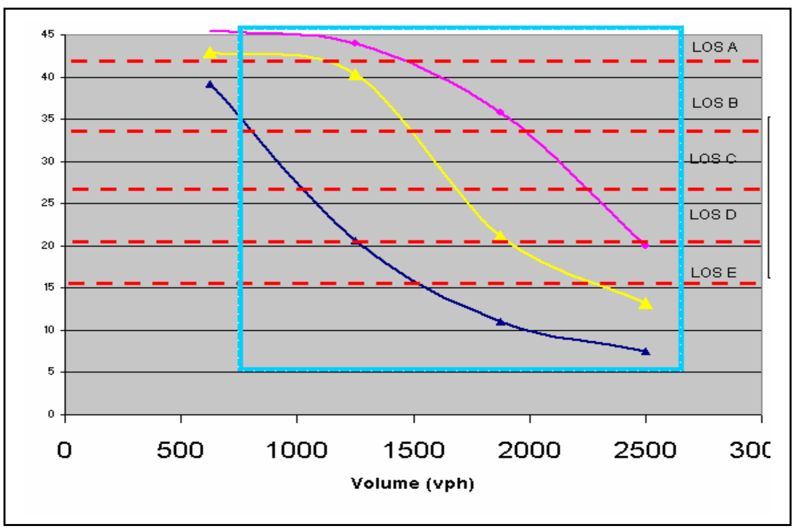


Figure B3. Example of a "High" Sensitivity Variable

Some variables and factors that are analyzed in this sensitivity are ones that are easily assumed and/or are not analyzed in enough detail in the 2000 HCM. Such characteristics include region (coastal, piedmont, mountainous), surrounding environment (urban, suburban, or rural), and terrain (level, rolling, mountainous) or specific grade (if known). The results follow for each of the three roadway facilities being analyzed for sensitivity of input variables: freeways, multi-lane highways, and urban streets.

FREEWAYS – 2000 HCM SUMMARY

The MOE used to determine LOS for freeway segments in the 2000 HCM is density, which is expressed in passenger cars per mile per lane (pc/mi/ln). The density of a segment is determined through the use of HCM Equation 23-4. The average passenger-car travel speed is determined using HCM Exhibit 23-3 which requires the use of an estimated or field-measured FFS, a speed-flow curve, and the flow rate of the segment (V_p). *Therefore, the LOS of a freeway is determined by its density, which is determined by its flow rate and average passenger-car speed, which is in turn determined by FFS and v/c ratio.* A summary of the 2000 HCM's sensitivity is below, followed by the analysis using HCS 2000.

Free flow speed

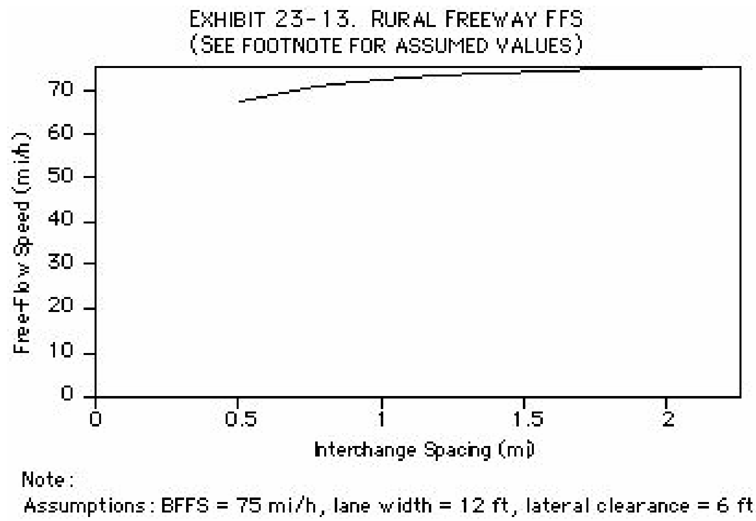
The first of these factors, FFS, is itself sensitive to average interchange spacing (in miles) and the number of lanes in each direction. In the case of rural freeways, just interchange spacing is a factor. HCM Exhibit 23-12 displays the effect that both interchange spacing and the number of lanes has on FFS for urban freeways.

EXHIBIT 23-12. URBAN FREEWAY FFS AND INTERCHANGE SPACING
(SEE FOOTNOTE FOR ASSUMED VALUES)

	Free-Flow Speed (mi/h)			
	Interchange Spacing (mi)			
Number of Lanes	0.50	0.75	1.25	1.75
2	58.0	61.4	64.0	65.2
3	59.5	62.9	65.5	66.7
4	61.0	64.4	67.0	68.2
5	62.5	65.9	68.5	69.7

Note:
Assumptions: BFFS = 70 mi/h, lane width = 12 ft, lateral clearance = 6 ft.

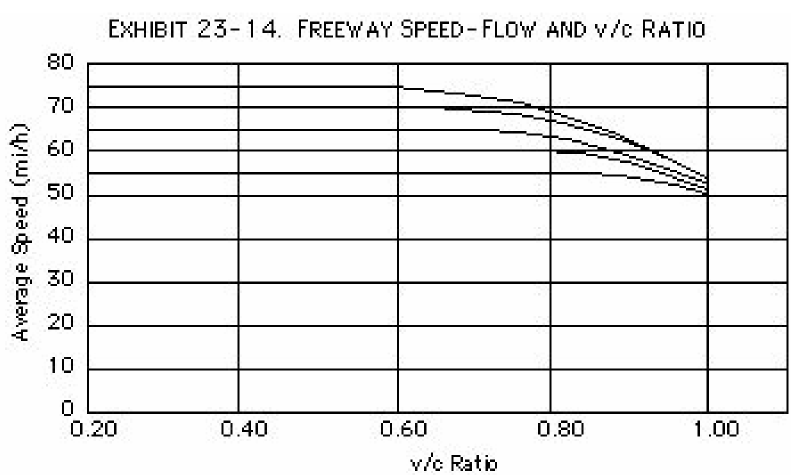
As one can see, FFS increases as the interchange spacing and/or number of lanes increases. The FFS for rural freeways on the other hand is sensitive to just interchange spacing and even then only spacing that is closer than 1.25 miles. HCM Exhibit 23-13 can be used to determine the FFS for a rural freeway given the average interchange spacing.



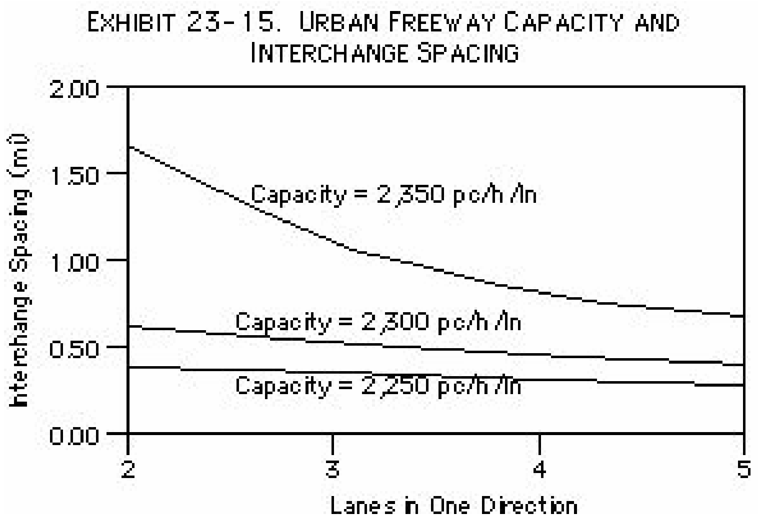
The HCM notes that both of these exhibits are based on assumptions about the roadway segment being analyzed. In the case of HCM Exhibit 23-12 (Urban Freeway FFS) a base FFS of 70 mi/h is assumed along with an ideal lane width of 12 feet and a lateral clearance of 6 feet. The assumptions for HCM Exhibit 23-13 (Rural Freeway FFS) are the same except a base FFS of 75 mi/h is assumed. If the segment being studied does not match these assumptions then adjustments would need to be carried out.

Volume/capacity ratio

The second of the two factors, v/c ratio, has little effect on passenger-car speed until it is greater than 54 to 80 percent depending on FFS. The HCM notes that FFS has more effect on speed at low v/c ratios than the v/c ratio itself. HCM Exhibit 23-14 shows the effect that varying v/c ratios have on the average speed.



As is evident by the graph, as v/c ratio increases past a certain point (54-80 percent, dependent on FFS) the average speed decreases. The v/c ratio itself is clearly determined in part by the capacity of the roadway being analyzed. For rural freeways with at least two lanes in one direction and interchange spacing of at least 2 miles, a capacity of 2,400 pc/h/ln is assumed. The HCM provides Exhibit 23-15 to determine the capacity for urban freeways with shorter interchange spacing or a different number of lanes.



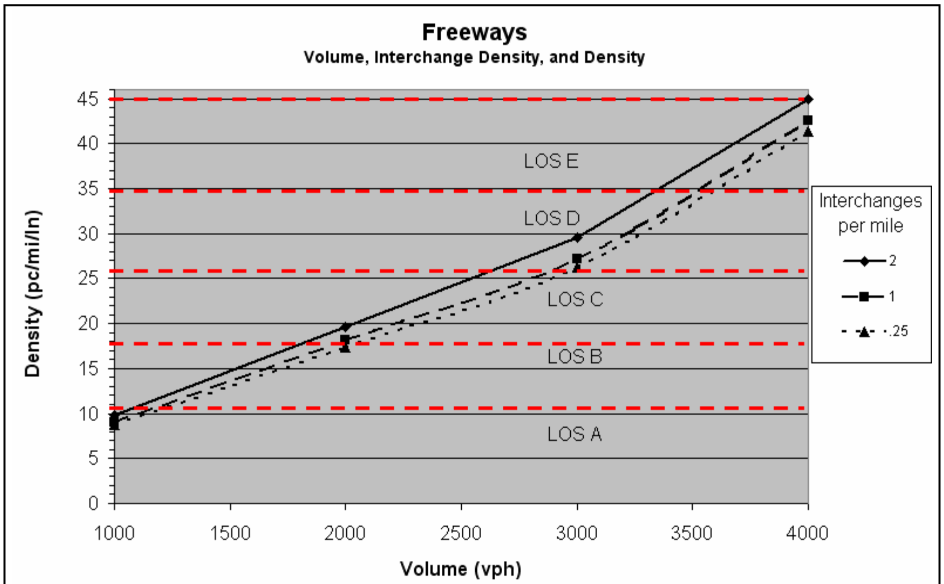
Accurate calibration of the freeway model requires data directly from the field that correctly describes the actual conditions. As the HCM states, studies by analysts have determined that there is no direct way to calibrate the capacity of a freeway system using field conditions. Therefore, estimated FFS and demand must be adjusted with field conditions in order to arrive at an accurate LOS determination. However, the HCM also points out that density can be measured directly in the field because all three of the factors that make up its units (number of cars per mile per lane) can be accurately observed and/or measured. This density can then be used to determine LOS directly.

FREEWAYS – HCS 2000 SUMMARY

A freeway has many variables and factors that are used to determine its LOS. The LOS of a freeway is measured by density in passenger cars per mile per lane (pc/mi/ln). Although there are many different variables used to decide the LOS of a freeway facility, a determination was made following the 2000 HCM sensitivity analysis that many variables needed further examination to see if reasonable defaults could be chosen. These include:

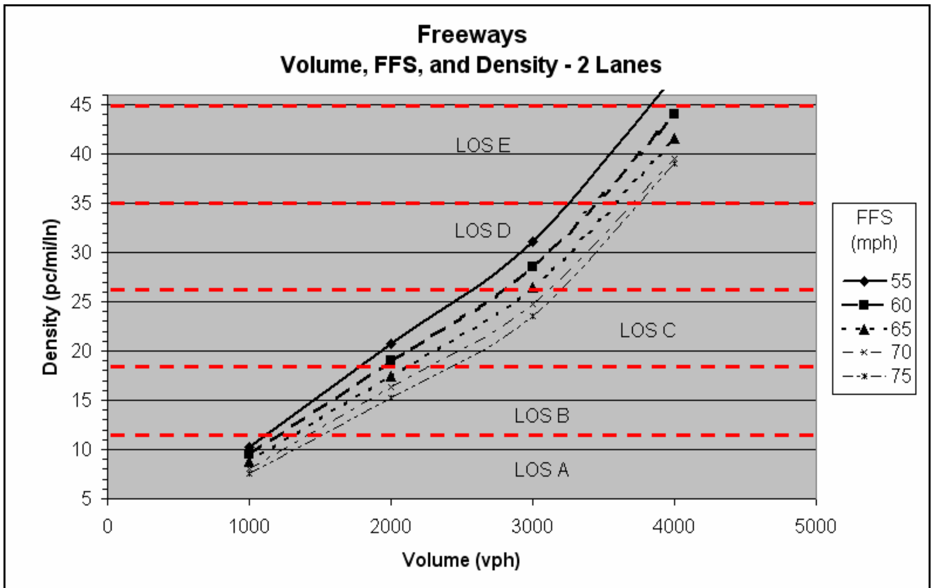
- Interchanges per mile
- Free flow speed (FFS)
- Percent trucks
- Grade
- Length of grade

Figures B4 and B5 refer to changes in the LOS for interchanges per mile and FFS for a two lane freeway facility, respectively. These two variables showed relatively small variations in the LOS as volumes increased. For freeways, these two figures showed "low" sensitivity, and therefore reasonable defaults can be obtained.



Note: Assumptions: BFFS = 70 mph, PHF = 0.9, 2 lanes, level terrain, truck/bus = 5%, RV = 0%, driver pop. Factor (fp) = 1, lane width = 12 ft, lateral clearance = 6 ft

Figure B4. Interchanges Per Mile



Note: Assumptions: PHF = 0.9, 2 lanes, level terrain, interchange density = 1.5/mile, truck/bus = 5%, RV = 0%, driver pop. Factor (fp) = 1, lane width = 12 ft, interchange density = 1.5/mile, lateral clearance = 6 ft

Figure B5. FFS for Two-Lane Freeway

As noted above, FFS is considered a "low" sensitivity variable for a 2-lane freeway. However, the graph can be deceiving because FFS becomes more sensitive as the number of lanes that the freeway has in operation increases. Therefore, FFS in combination with number of lanes constitutes a medium sensitivity variable. An example of this is provided through a comparison of Figure B5 and the 5-lane freeway facility in Figure B6 below. The expected drop in density for a given volume and hence improvement in LOS constitutes FFS as being a "medium" sensitivity variable because it varies by no more than plus or minus one LOS.

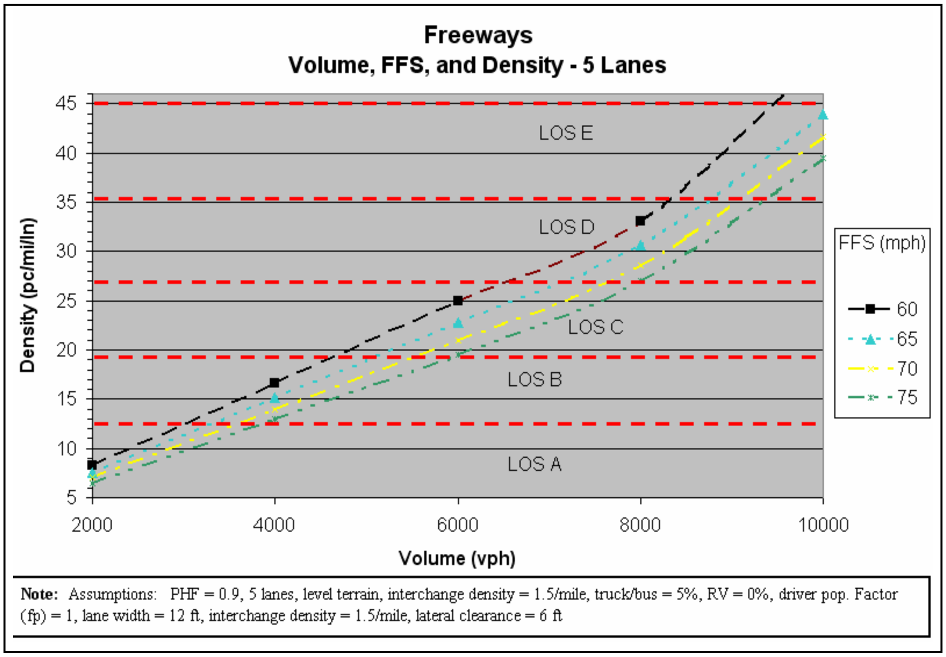
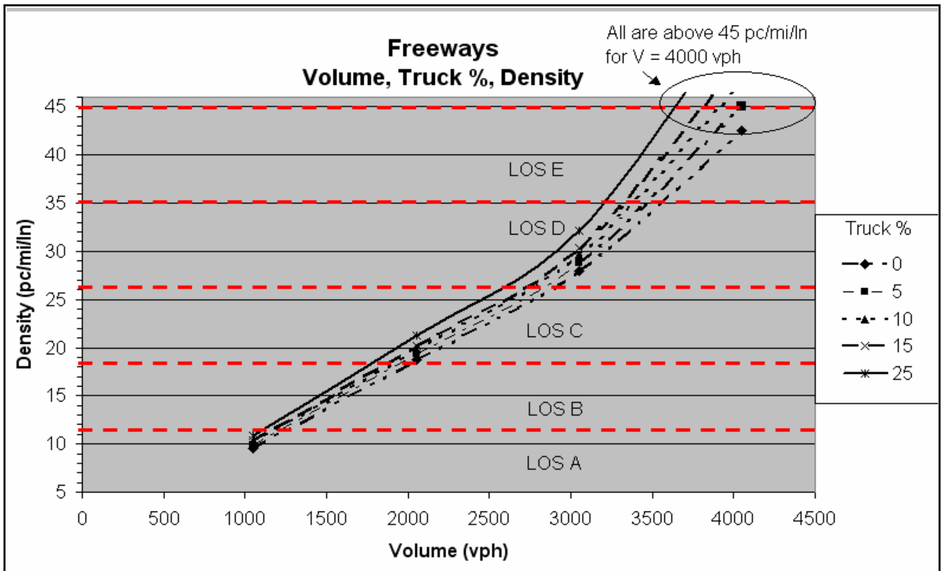


Figure B6. FFS for Five-Lane Freeway

It was mentioned earlier that "medium" sensitivity variables should be considered as *possibly needing* more data to determine good default values. Although FFS has "medium" sensitivity, more data is not needed. The FFS is somewhat sensitive when based on the number of lanes; however, it is fairly easy to assume (default) this variable based on the environment (urban, suburban, rural, etc.) where the facility is going to be constructed.

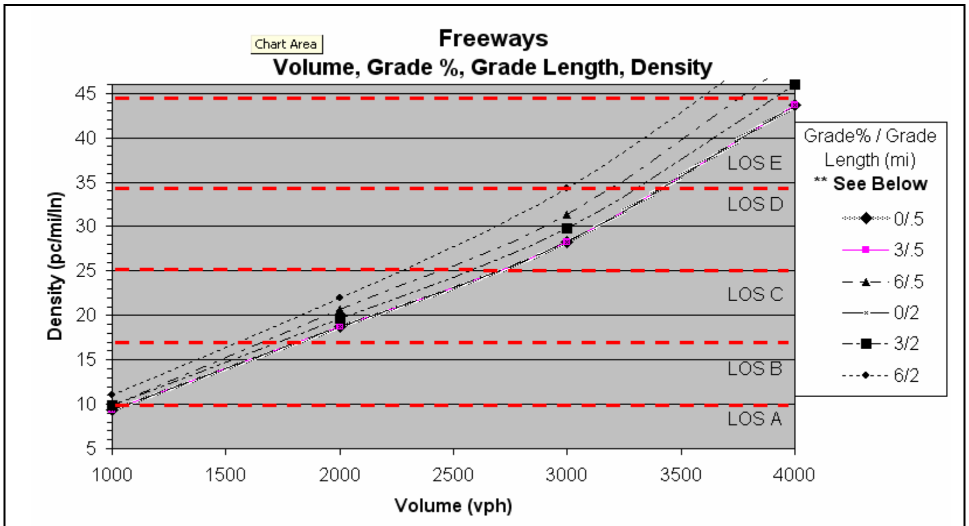
The amount of trucks that are contained on a freeway segment does affect capacity. However, on most freeway facilities, trucks do not have a significant affect on the LOS, as shown in Figure B7. This is because most freeways are on terrains that have low percent grades for relatively short distances. Therefore, on relatively flat freeways the percentage of trucks is considered a "low-medium" sensitivity variable.



Note: Assumptions: BFFS = 70 mph, PHF = 0.9, 2 lanes, level terrain, interchange density = 1.5/mile, RV = 0%, driver pop. Factor (fp) = 1, lane width = 12 ft, lateral clearance = 6 ft

Figure B7. Percent Trucks

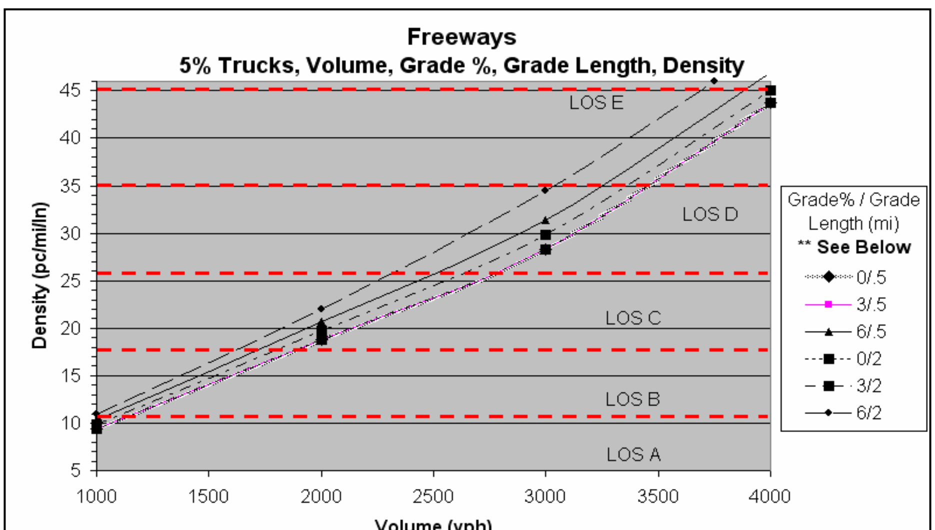
Figure B8 shows the effect of grade on a freeway. This graph is similar to that of Figure B7 because percentage of trucks is a contributing factor. However, grade by itself does not seem to have an affect on this type of roadway facility because it is only analyzed at five percent trucks. This gives an inaccurate representation of the affect of trucks and grades on a freeway facility. Therefore, a more accurate representation of all cases along the various spectrums of grades is needed to show the correlation of grades as the percentage of trucks increase.



Note: Assumptions: BFFS = 70 mph, PHF = 0.9, 2 lanes, truck/bus =5%, interchange density = 1.5/mile, RV = 0%, driver pop. Factor (fp) = 1, lane width = 12 ft, lateral clearance = 6 ft
**** 0/2, 3/.5, 0/.5 overlap**

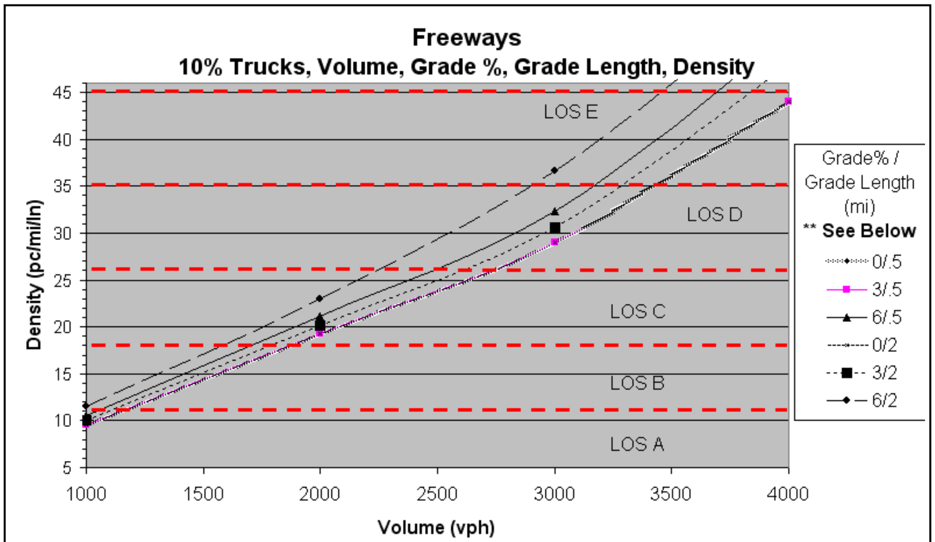
Figure B8. Grade, Length of Grade

Not all freeways are built in areas where grade is not a significant concern. The length of grade, percent grade, and percent of trucks are all interconnected variables that have a "medium" sensitivity in areas where a considerable increase or decrease in percent grade occurs. Figures B9–B13 are a very good representation of the effects of these interrelated variables. Seen below, they show the graduation of variability as the percent of trucks increases from five to twenty-five percent at different grades and length of grade.



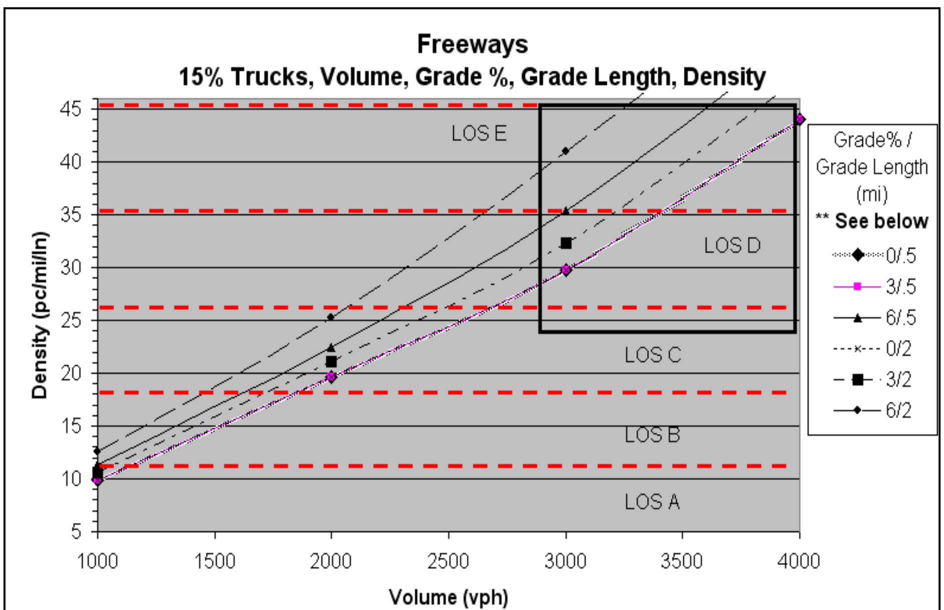
Note: Assumptions: BFFS = 70 mph, PHF = 0.9, 2 lanes, interchange density = 1.5/mile, RV = 0%, driver pop. Factor (fp) = 1, lane width = 12 ft, lateral clearance = 6 ft
**** 0/2, 3/.5, 0/.5 all overlap**

Figure B9. Five Percent Trucks, Grade, Grade Length



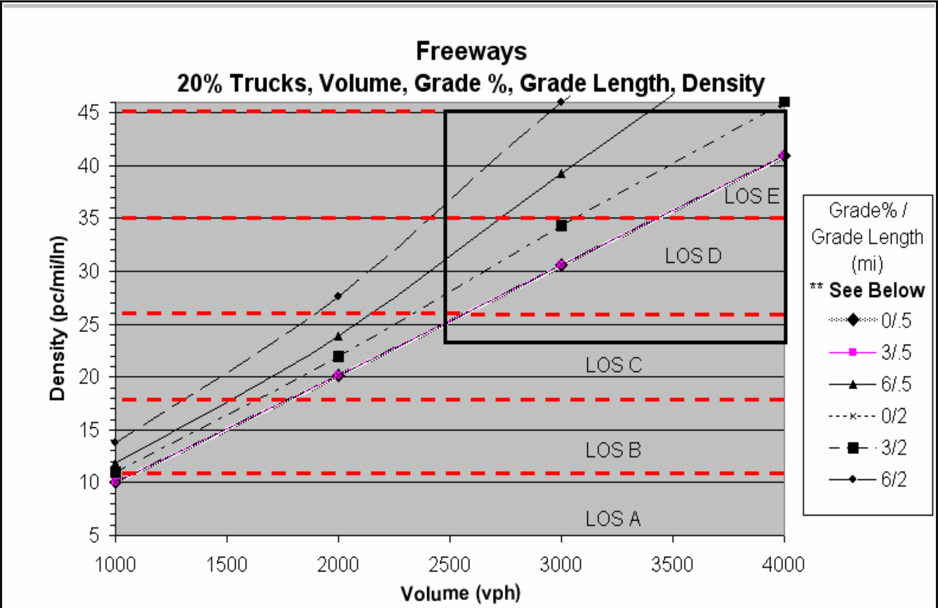
Note: Assumptions: BFFS = 70 mph, PHF = 0.9, 2 lanes, interchange density = 1.5/mile, RV = 0%, driver pop. Factor (fp) = 1, lane width = 12 ft, lateral clearance = 6 ft
**** 0/2, 3/.5, 0/.5 all overlap**

Figure B10. Ten Percent Trucks, Grade, Grade Length



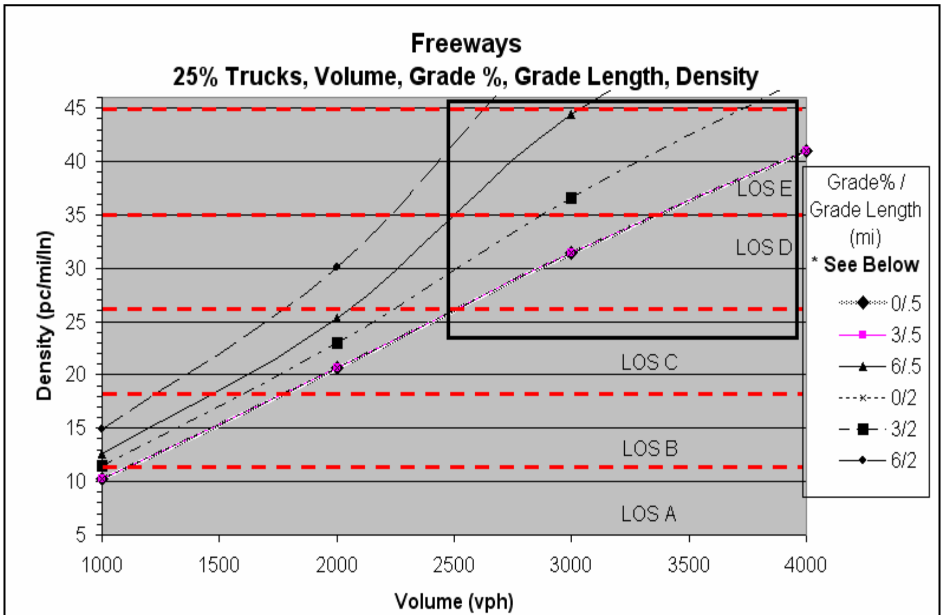
Note: Assumptions: BFFS = 70 mph, PHF = 0.9, 2 lanes, interchange density = 1.5/mile, RV = 0%, driver pop. Factor (fp) = 1, lane width = 12 ft, lateral clearance = 6 ft
**** 0/2, 3/.5, 0/.5 all overlap**

Figure B11. Fifteen Percent Trucks, Grade, Grade Length



Note: Assumptions: BFFS = 70 mph, PHF = 0.9, 2 lanes, interchange density = 1.5/mile, RV = 0%, driver pop. Factor (fp) = 1, lane width = 12 ft, lateral clearance = 6 ft
**** 0/2, 3/.5, 0/.5 all overlap**

Figure B12. Twenty Percent Trucks, Grade, Grade Length



Note: Assumptions: BFFS = 70 mph, PHF = 0.9, 2 lanes, interchange density = 1.5/mile, RV = 0%, driver pop. Factor (fp) = 1, lane width = 12 ft, lateral clearance = 6 ft
**** 0/2, 3/.5, 0/.5 all overlap**

Figure B13. Twenty-Five Percent Trucks, Grade, Grade Length

These three variables show a considerable range in the LOS. Because they show a "medium" sensitivity, consideration is given into whether more data should be collected to determine appropriate default values. In this particular circumstance, it was decided that more data would need to be collected because grades, length of grades, and percentage trucks are not easily defaulted by their roadway characteristics and environment.

MULTILANE HIGHWAYS – 2000 HCM SUMMARY

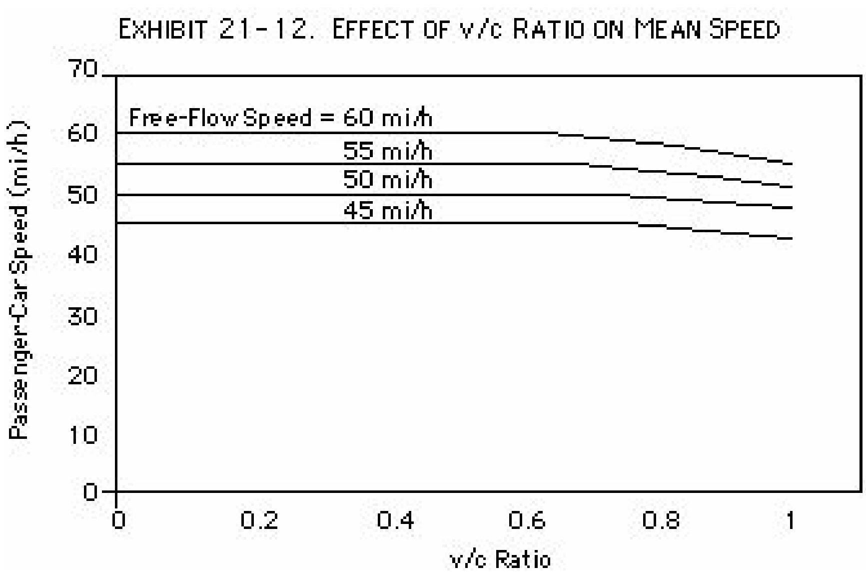
Although multilane highways differ from the previously discussed freeway segments in that they have less access control, the MOE for LOS for both facilities is density in passenger cars per mile per lane (pc/mi/ln). The density of flow is determined using HCM Equation 21-5 which states:

$$D = \frac{v_p}{S} \qquad (21\text{-}5)$$

where

D = density (pc/mi/ln),
v_p = flow rate (pc/h/ln), and
S = average passenger-car travel speed (mi/h).

The affect that v/c ratio has on passenger car speed (and therefore density and LOS through use of HCM Equation 21-5) is shown in HCM Exhibit 21-12.



The exhibit shows that as v/c ratio increases (i.e. as demand increases), average passenger-car speed decreases and, therefore, the density increases because fewer vehicles are moving through the segment and are instead being delayed within the length of the segment. However, the HCM notes that speed is not affected by the v/c ratio until the demand is at least 70% of the capacity for most speeds. This number is even higher, 90%, for lower-speed segments.

MULTILANE HIGHWAYS – HCS 2000 SUMMARY

Many different types of variables define multilane highway facilities. Some of these differ from that of a freeway, while some remain the same. Although many variables differ, the LOS indicator for a multilane facility remains the same as that of a freeway, and is given in passenger cars per mile per lane (pc/mi/ln). Based on the HCM sensitivity analysis, the following variables needed further examination in order to see if reasonable defaults could be determined:

- Access points per mile
- Divided facility
- Undivided facility
- Base free flow speed (BFFS)
- Percent trucks
- Grade
- Length of grade

Figures B14, B15, and B16 refer to changes in the LOS for access points per mile, divided and undivided facilities, and BFFS, respectively. These three variables show slight variations in the LOS as volumes incrementally increased. For multilane highways, these variables all showed "low" sensitivity on the LOS, thus reasonable defaults can be found.

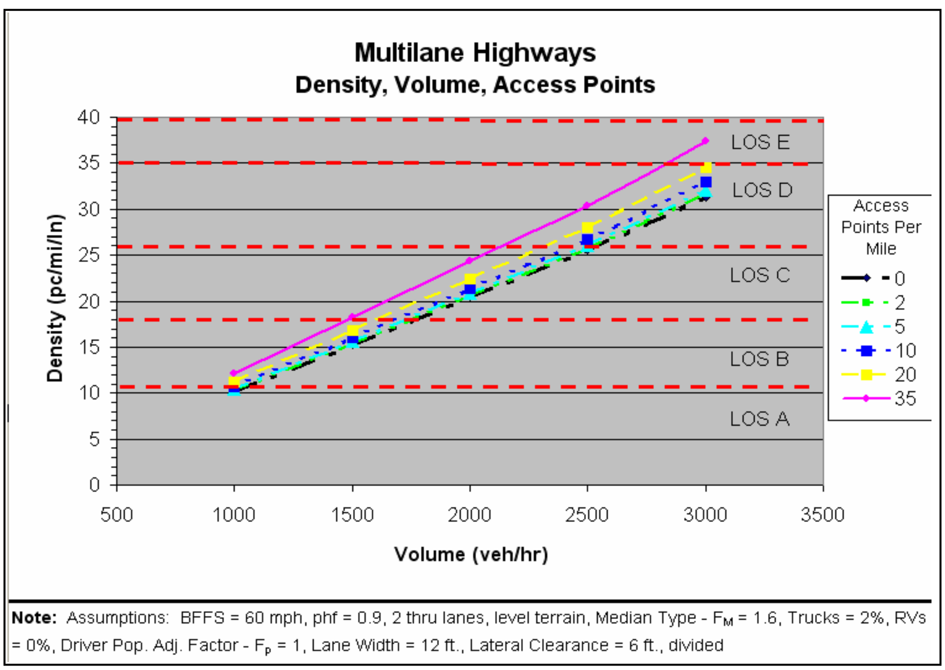
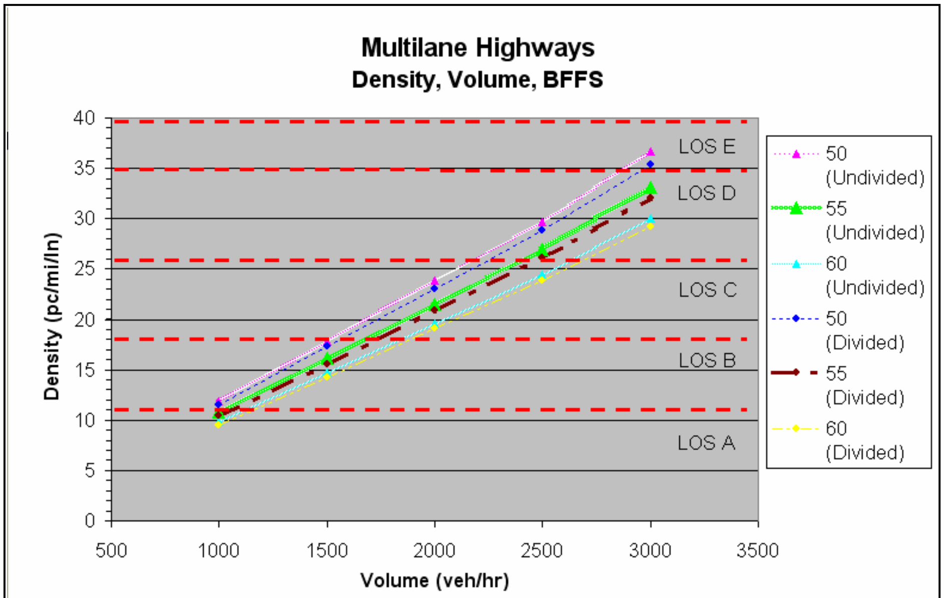


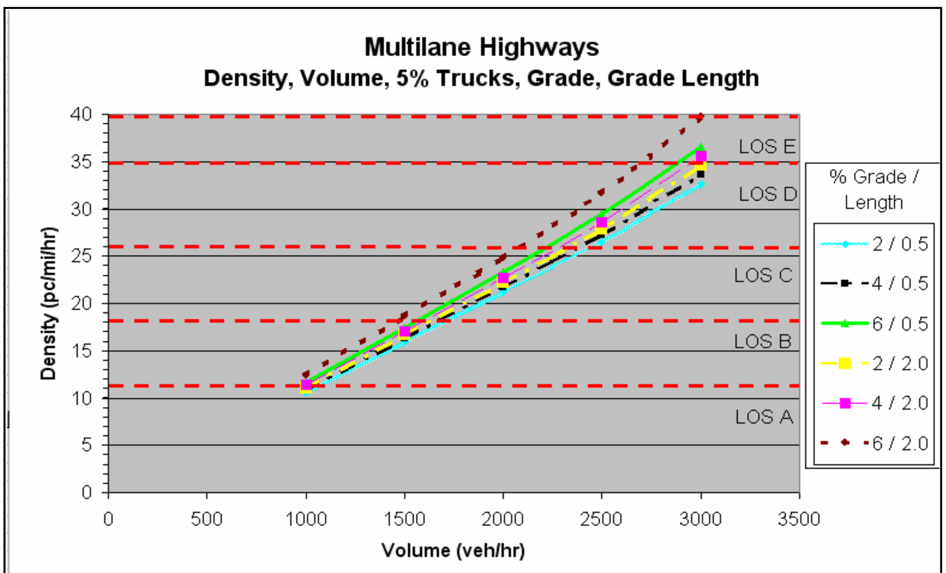
Figure B14. Access Points



Note: Assumptions: BFFS = 60 mph, phf = 0.9, 2 thru lanes, level terrain, Median Type - F_M = 1.6, Trucks = 2%, RVs = 0%, Driver Pop. Adj. Factor - F_p = 1, Lane Width = 12 ft., Lateral Clearance = 6 ft., 5 access points/mi

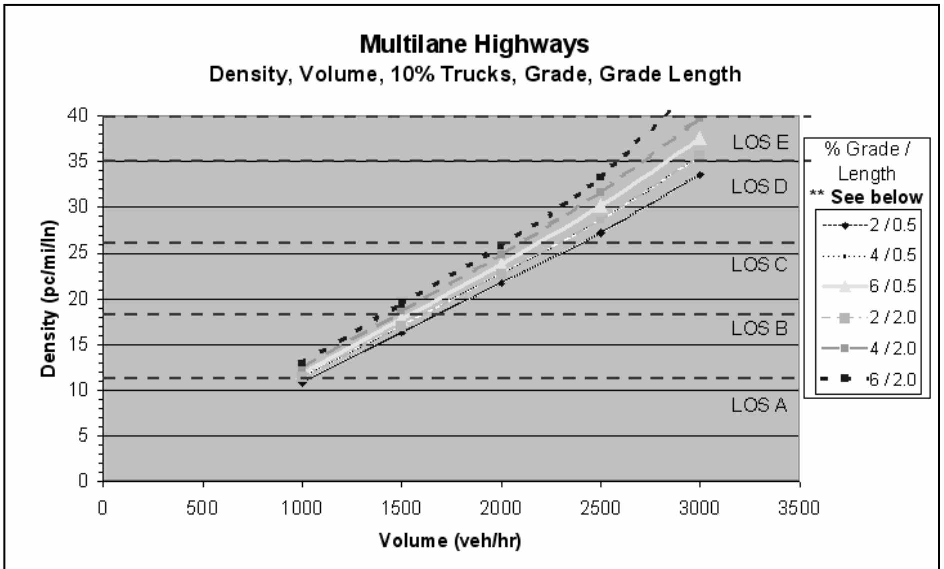
Figure B15. Divided and Undivided Facility, BFFS

As with freeways, multilane highways are not sensitive to grade, length of grade, or trucks when analyzed separately, but are when variations are made interchangeably between the three. All three of these variables have a high degree of association and show a "medium" sensitivity. Figures B16–B20 show the graduation of variability as the percent of trucks increases from five to twenty-five percent.



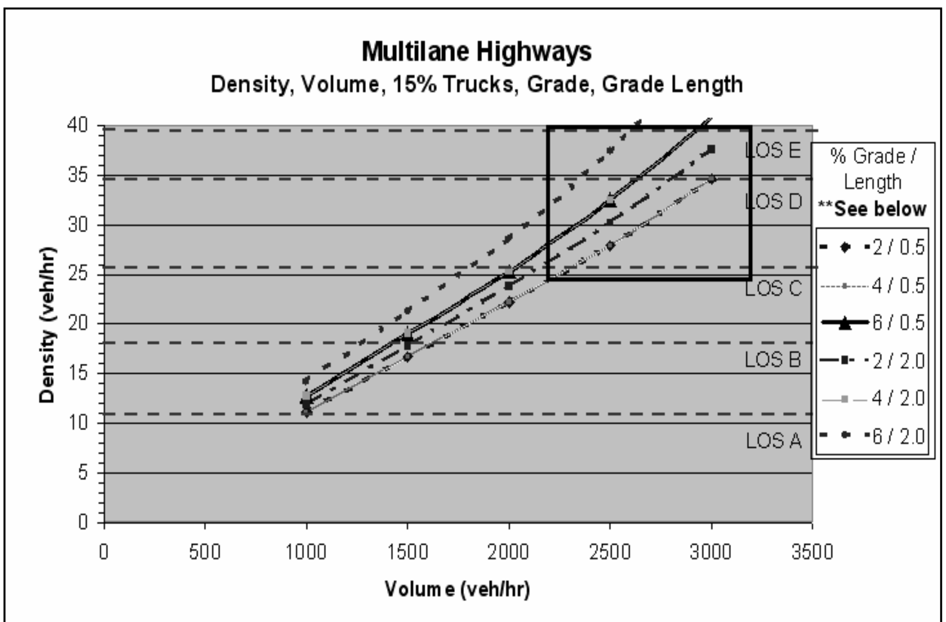
Note: Assumptions: BFFS = 55 mph, phf = 0.9, 2 thru lanes, 5 Access points, Median Type - F_M = 0, RVs = 0%, Driver Pop. Adj. Factor - F_p = 1, Lane Width = 12 f, lateral clearance = 6ft., divided

Figure B16. Five Percent Trucks, Grade, Grade Length



Note: Assumptions: BFFS = 55 mph, phf = 0.9, 2 thru lanes, 5 Access points, Median Type - F_M = 0, RVs = 0%, Driver Pop. Adj. Factor - F_p = 1, Lane Width = 12 f, lateral clearance = 6ft., divided
**** 4/0.5 - 2/2.0 overlap**

Figure B17. Ten Percent Trucks, Grade, Grade Length



Note: Assumptions: BFFS = 55 mph, phf = 0.9, 2 thru lanes, 5 Access points, Median Type - F_M = 0, RVs = 0%, Driver Pop. Adj. Factor - F_p = 1, Lane Width = 12 f, lateral clearance = 6ft., divided
**** 6/0.5 - 4/2.0 and 4/0.5 - 2/0.5 overlap**

Figure B18. Fifteen Percent Trucks, Grade, Grade Length

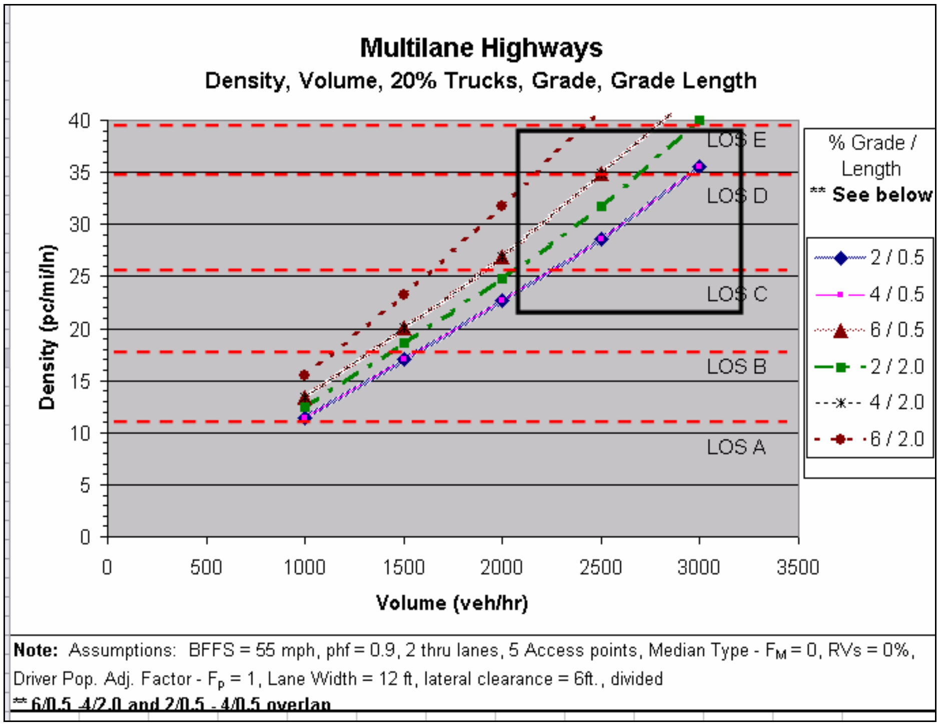


Figure B19. Twenty Percent Trucks, Grade, Grade Length

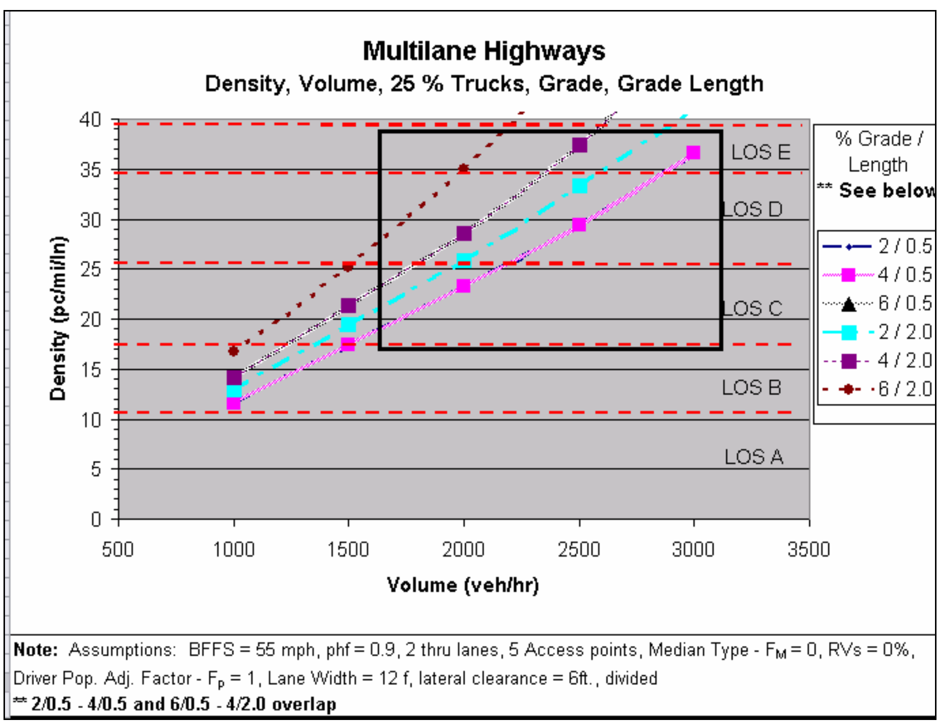


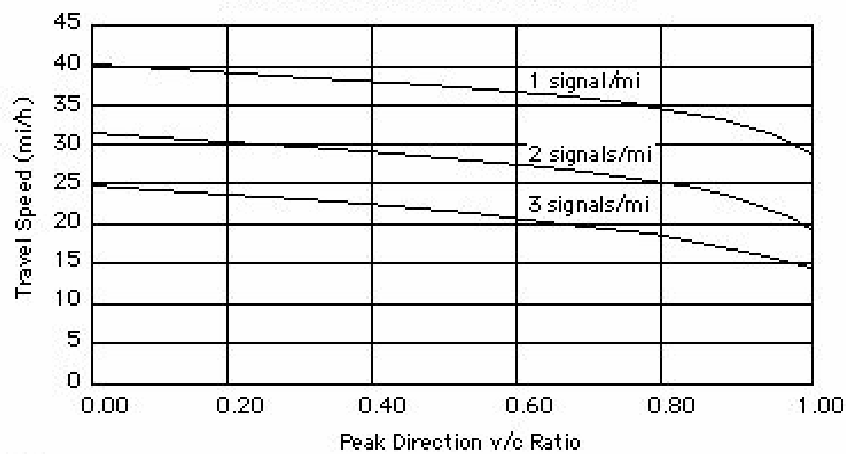
Figure B20. Twenty-Five Percent Trucks, Grade, Grade Length

At high vehicle volumes, there is a noticeable increase in the variability of LOS by changes in the percent grade, length of grade, and percentage of trucks. This is especially true at a percentage of trucks greater than fifteen, were the range in the LOS becomes quite large. Therefore, as with freeways, more data will need to be collected. Defaults for these variables are not easy to assume by roadway characteristics or environmental factors.

URBAN STREETS (ARTERIALS) – 2000 HCM SUMMARY

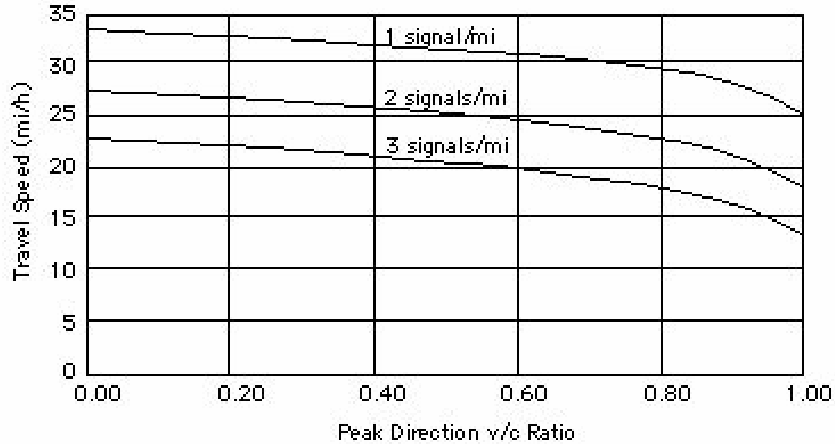
In the 2000 HCM, the measure of effectiveness (MOE) used to determine LOS for urban streets is the average travel speed of the vehicles along the street, expressed in mi/hr. Input variables that affect the average travel speed are FFS, v/c ratio, signal density, and the urban street class to which the examined roadway belongs. As stated previously in the literature review, the methodology does not directly account for on-street parking, access control, grades or capacity constraints between intersections, medians or two-way left turn lanes, queues backing into previous intersections, or cross-street congestion blocking through traffic. HCM Exhibits 15-8 through 15-11 show the affect that intersection v/c ratio and signal spacing have on travel speed for each of the four urban street classes (Classes I-IV).

EXHIBIT 15-8. SPEED-FLOW CURVES FOR CLASS I URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



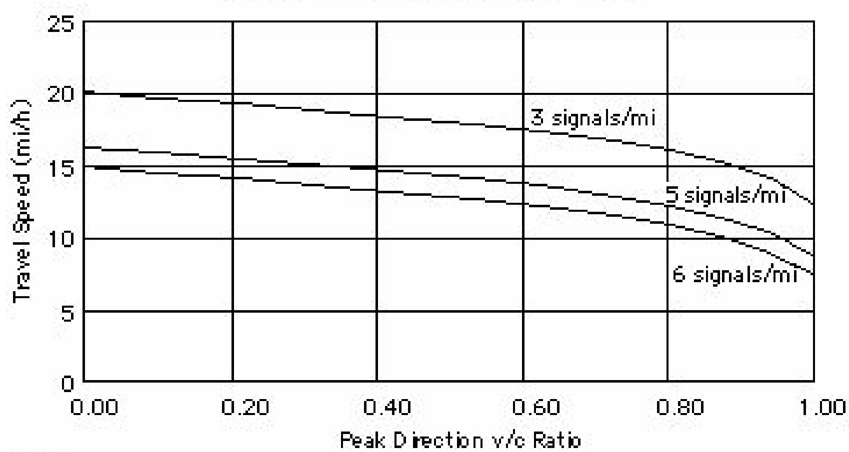
Note:
Assumptions: 50-mi/h midblock FFS, 6-mi length, 120-s cycle length, 0.45 g/C. Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

EXHIBIT 15-9. SPEED-FLOW CURVES FOR CLASS II URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



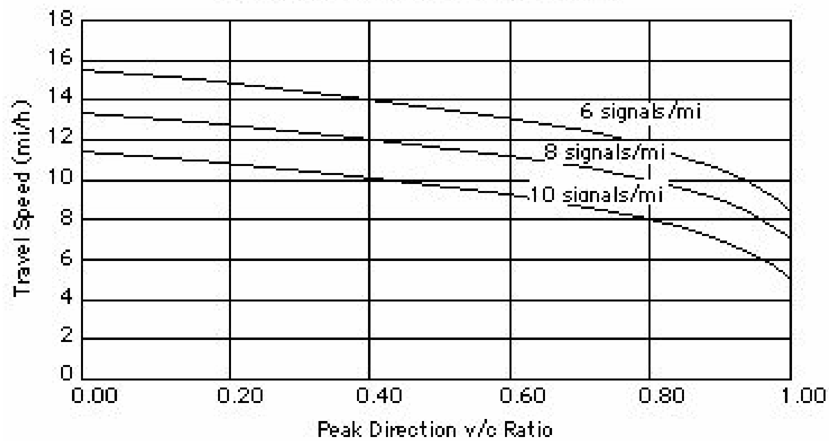
Note:
Assumptions: 40-mi/h midblock FFS, 6-mi length, 120-s cycle length, 0.45 g/C, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

EXHIBIT 15-10. SPEED-FLOW CURVES FOR CLASS III URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumptions: 35-mi/h midblock FFS, 6-mi length, 120-s cycle length, 0.45 g/C, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

EXHIBIT 15-11. SPEED-FLOW CURVES FOR CLASS IV URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)

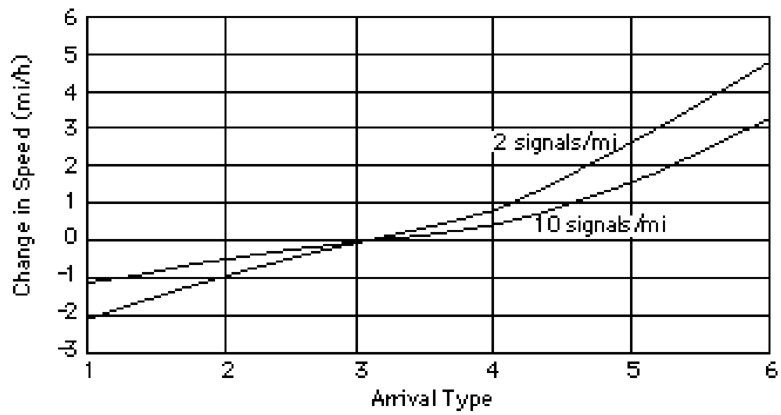


Note:
Assumptions: 30-mi/h midblock FFS, 6-mi length, 120-s cycle length, 0.45 g/C, Arrival Type 4, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

As is evident from the curves, travel speed decreases as signal density and v/c ratio increase. This shows that the increased amount of friction contributed by the intersections (right turning vehicles, points of entry for vehicles on side streets, and most importantly, increased opportunities for through vehicles to encounter a red light) and the congestion that a high v/c ratio reflects, will reduce the average travel speed and thus the LOS on all classes of urban streets.

The HCM uses several assumptions in computing these curves, including FFS, length of segment, cycle length, g/C ratio, arrival type, adjusted saturation flow rate, number of lanes, length of analysis period and the type of signal operation used for the intersection. These assumptions are stated below each of the exhibits. Therefore, if the street displays characteristics different from these assumptions, such as four lanes instead of the assumed two, then the curves would not be as accurate a measure of average travel speed, and therefore of LOS, unless the proper adjustments are made. HCM Exhibit 15-12, depicting a Class III highway, provides an adjustment value to be applied to the average travel speed arrived at in HCM Exhibit 15-10 if the assumed arrival type is different from that which actually exists.

EXHIBIT 15-12. CHANGE IN MEAN SPEED FOR ARRIVAL TYPES
(SEE FOOTNOTE FOR ASSUMED VALUES)



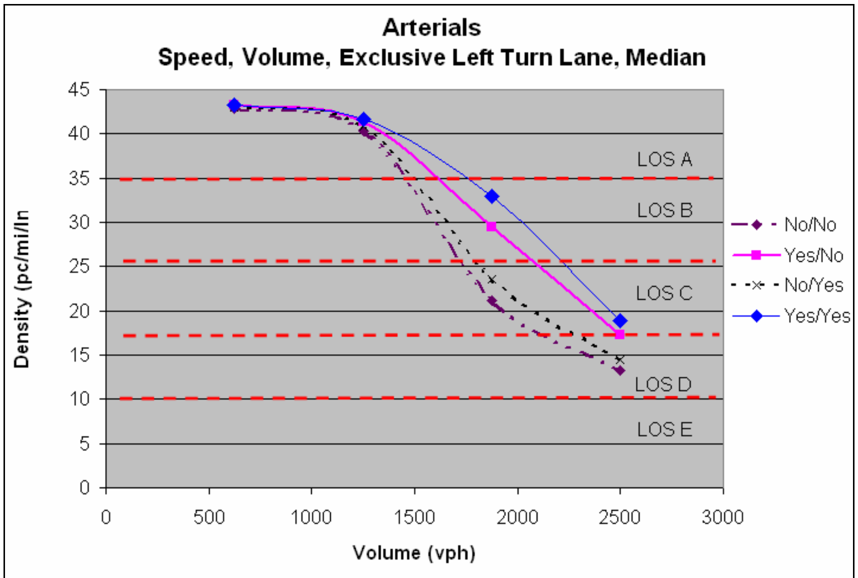
Note:
Assumptions: Urban street Class III, 35-mi/h midblock FFS, 6-mi length, 120-s cycle, 0.45 g/C, pretimed signals, 0.925 peak-hour factor (PHF), exclusive left-turn lanes, 12 percent left turns.

URBAN STREETS (ARTERIALS) – HCS 2000 SUMMARY

Urban streets, or arterials, are dissimilar in several aspects compared to multilane highway facilities. Signalization is the biggest difference; however, the urban classification is also a noticeable variation. Another distinguishing characteristic is the LOS indicator, which is average travel speed (mph). These differences account for new variables being analyzed for sensitivity for this type of highway. Based on the HCM sensitivity analysis, variables being further analyzed for this roadway facility to better determine defaults include:

- Exclusive left turn lane
- Median
- Number of signals per mile
- Urban class
- g/C ratio

Shown in Figure B21, the interrelated variables of exclusive left turn lanes and medians results in a "low" sensitivity with respect to the LOS for an urban street facility.



Note: Assumptions: Urban Class 1, 5000 AADT, 3 intersections, 6-mi length, 0.45 g/C 120-s cycle length, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation, 20% left turns from exclusive lanes

Figure B21. Exclusive Left Turn Lane and Median

Urban street class, when defining an arterial, is often confusing and very hard to understand. However, when modeling arterials, the urban street classification scale, broken up into four separate classifications, is somewhat sensitive in determining the LOS. This is shown in the box below in Figure B22. This variable shows a "medium" sensitivity based on the graph; therefore, a decision needs to be made on whether or not data should be collected.

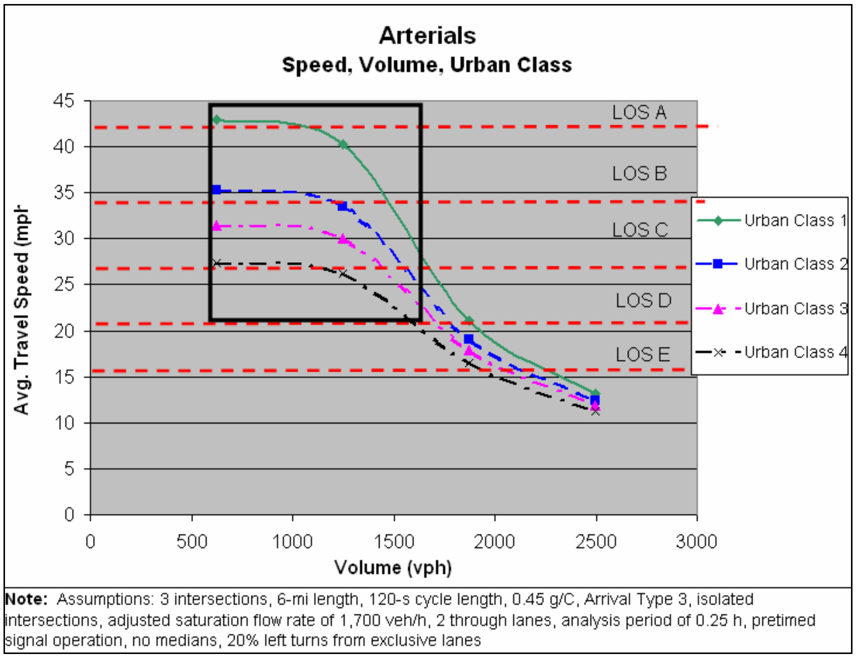
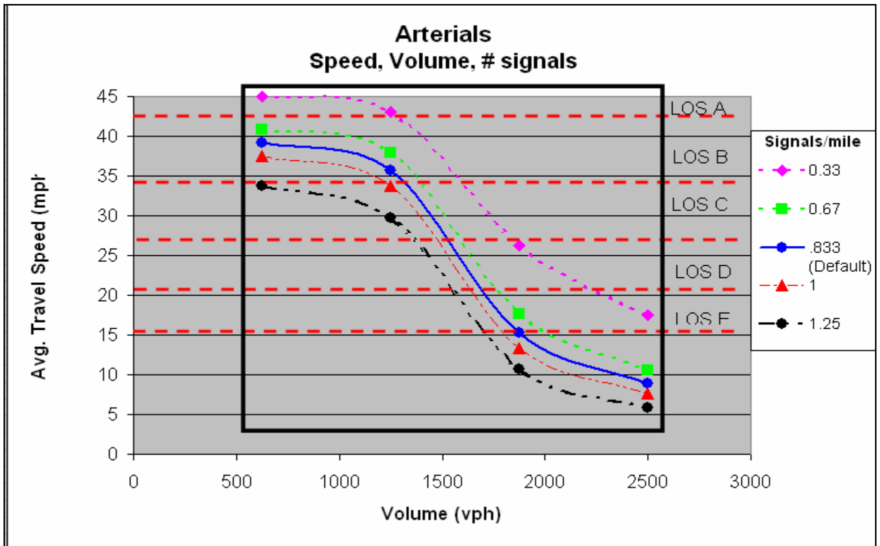


Figure B22. Urban Classification

The urban class scale is broken up into four classifications: I, II, III, and IV. Each class is defined by a functional category (principal or minor arterial) and a design category (high-speed, suburban, intermediate, or urban). When looking at Figure B22, the sensitivity is somewhat deceiving because it shows this variable as having a "medium" sensitivity. Although this is the case, the variable can be easily defined based on its functional and design category. Therefore, no more data is needed to determine defaults.

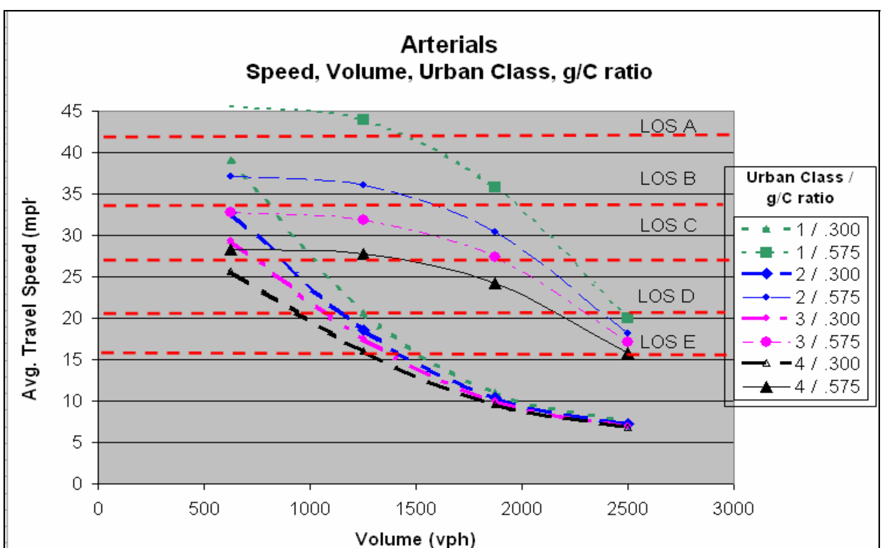
Figure B23 shows the number of signals per mile on an urban street system. Variability in the LOS is fairly constant along the entire spectrum of volumes. Shown by the box, this constant variation is greater than plus/minus one LOS, which makes it a "high" sensitivity variable. Therefore, this will need further data collection to make assumptions on default variables on this roadway system.



Note: Assumptions: Urban Class 1, 5000 AADT, 6-mi length, 0.45 g/C 120-s cycle length, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation, no median

Figure B23. Signals Per Mile

The effective green to cycle length ratio (g/C) is a good measure of the efficiency of a signalized intersection. It is usually directly correlated with the number of phases at an intersection. The more phases an intersection has, the lower the g/C ratio usually is for an approach. The g/C ratio is not easily defaulted by its urban class or any other variable pertaining to arterials. Figure B24 compares the four urban classes with approximate minimum and maximum g/C ratios. This graph shows the huge sensitivity that the g/C ratio has on an arterial system.



Note: Assumptions: 3 intersections, 6-mi length, 120-s cycle length, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation, no medians, 20% left turns from exclusive lanes

Figure B24. Effective Green to Cycle Length Ratio (g/C)

Figures B25–B28 separate each urban class with approximate minimum and maximum g/C ratios. The assumed default value for the g/C ratio used in the HCM 2000 is also given to show the range that the minimum and maximum values have about the standard default. A box inscribed within each figure shows the "high" sensitivity areas.

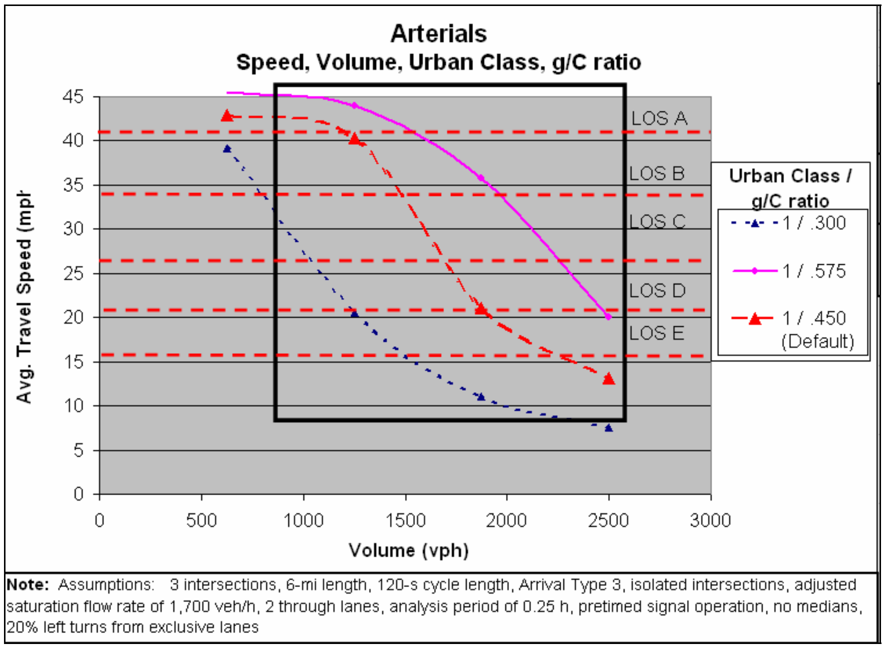


Figure B25. Urban Class I, Effective Green to Cycle Length Ratio (g/C)

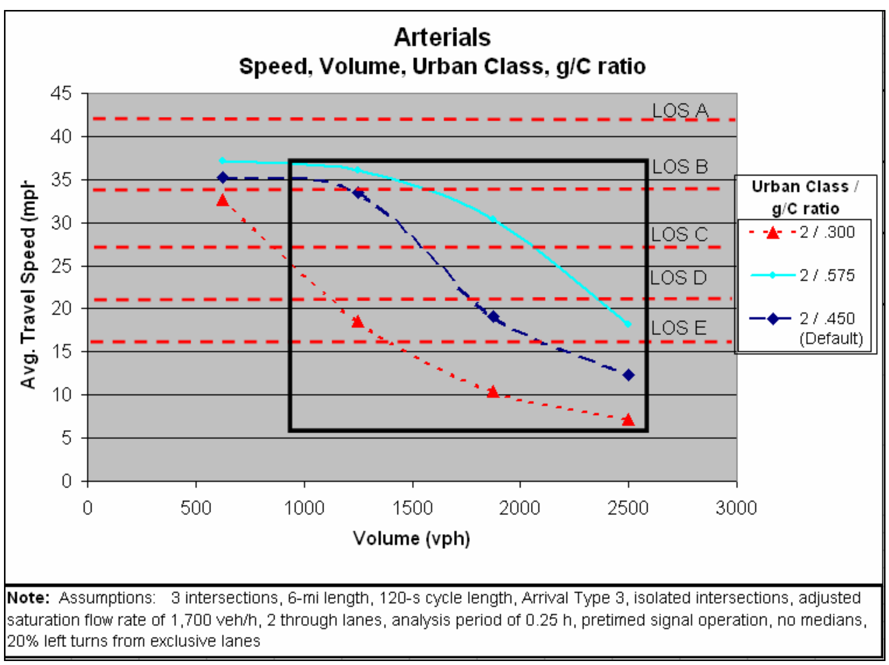


Figure B26. Urban Class II, Effective Green to Cycle Length Ratio (g/C)

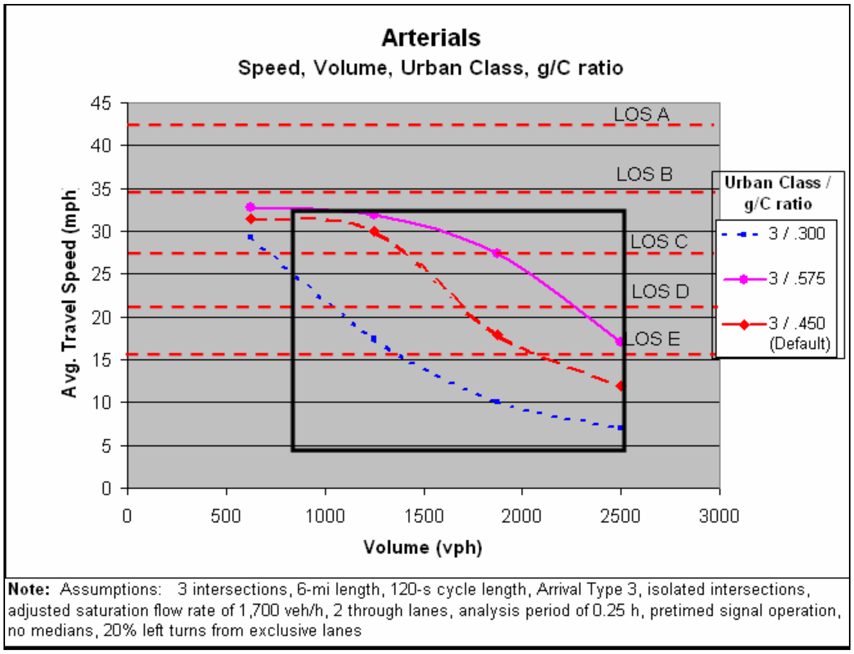


Figure B27. Urban Class III, Effective Green to Cycle Length Ratio (g/C)

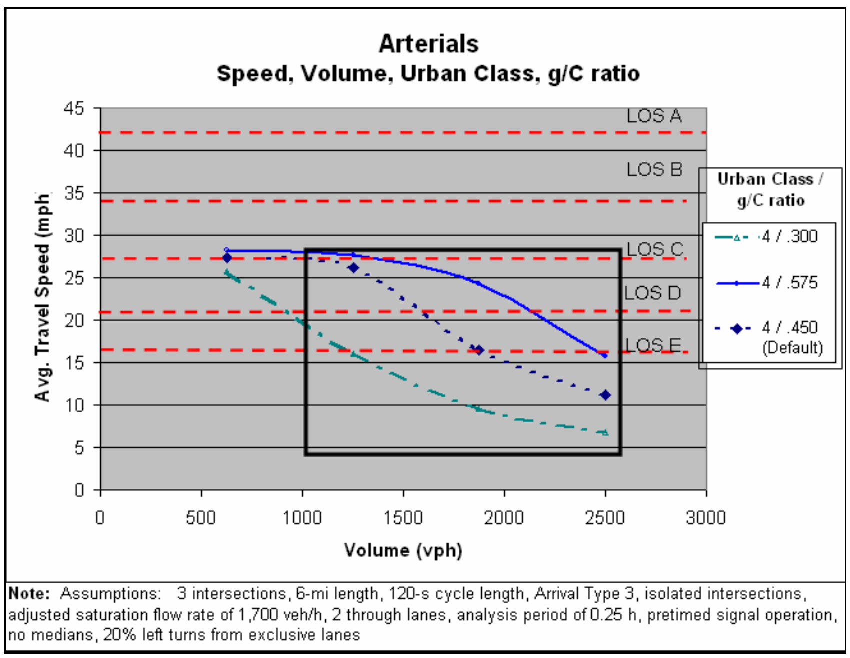


Figure B28. Urban Class IV, Effective Green to Cycle Length Ratio (g/C)

The g/C ratio combined with an urban class is obviously highly sensitive. Because the g/C ratio is very hard to default, further examination and data collection will need to be done on different urban class signalized intersections in order to determine possible defaults.

TWO-LANE HIGHWAYS – 2000 HCM SUMMARY

Two-lane highways are divided into two classes in the HCM. Class I highways are segments in which the key element is efficient mobility and therefore the LOS is defined by both percent time-spent-following and average travel speed. In Class II highways however, access is more important and therefore LOS is determined by percent time-spent-following alone.

The percent time-spent-following is determined by using the segment's demand flow rate, directional distribution of traffic and percentage of no-passing zones. Demand flow rate (v_p) is determined through the use of HCM Equation 20-3, which includes adjustments for both grade and heavy vehicles.

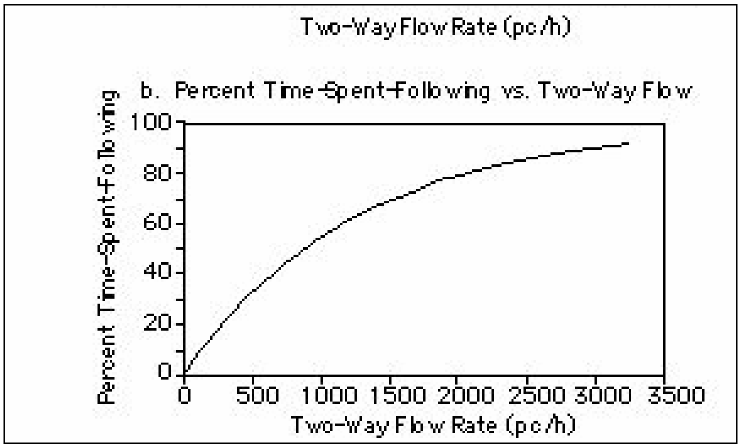
The grade adjustment factor (f_G) takes into account the effect that terrain has on both percent time-spent-following as well as travel speeds. The factor increases as the flow rate increases if the segment is on a rolling terrain. If the terrain is level then the factor is always 1.00 regardless of the flow rate of the segment being analyzed.

The heavy vehicle adjustment factor (f_{HV}) is determined through the use of HCM Equation 20-4, which includes variables that account for the proportion of trucks and RVs in the traffic stream as well as the passenger car equivalents for each based on either level or rolling terrain and the flow rate (HCM Exhibit 20-9). As the flow rate increases, the passenger car equivalents decrease for trucks in both rolling and level terrain while they stay the same for RVs. A higher proportion of trucks and/or RVs and a higher passenger car equivalent rate yield a smaller f_{HV}, which leads to a larger v_p value.

Finally, the v_p value arrived at in HCM Equation 20-3 is then used to determine the base percent time-spent-following for both directions of travel combined (BPTSF) through the use of HCM Equation 20-7. Therefore, a larger v_p yields a higher base percent time-spent-following.

The effects of the directional distribution of traffic and the percentage of no-passing zones are combined into one factor, $f_{d/np}$, which is determined through the use of HCM Exhibit 20-12.

As is evident by the exhibit, the adjustment factor increases as the percentage of no passing zones increases. The factor is also sensitive to the directional split and increases as the split moves further away from a 50/50 distribution. Furthermore, as two-way flow rate increases, the adjustment decreases. The reason for the decrease in the adjustment of PTSF as volumes get higher can be explained by Exhibit 12-6. At low volumes, given a large percentage of no passing zones, there is a significant effect on how much time a driver spends following a vehicle. At high volumes, PTSF is already extremely high, and given a large percentage of no passing zones, does not significantly increase the PTSF.



HCM Exhibit 12-6

These two factors, BPTSF and $f_{d/np}$, are then summed to arrive at the percent time-spent-following, PTSF (HCM Equation 20-6), which means that a higher BPTSF and/or a higher $f_{d/np}$ leads to a higher PTSF, and therefore a lower LOS for Class II highways using HCM Exhibit 20-4.

As mentioned above, the LOS for Class I highways is not only dependent on PTSF, but also on the average travel speed (ATS) for the analyzed segment. The ATS is determined using the demand flow rate (v_p, which is found the same way as it was for the PTSF above except that the passenger car equivalents are taken from Exhibit 20-10 instead of Exhibit 20-9), the FFS, and an adjustment factor for the percentage of no-passing zones. The FFS is estimated using either HCM Equation 20-1 or 20-2, with the former being used if FFS is determined through field measurements and the latter if it is determined indirectly. The field method, HCM Equation 2-1, is sensitive to the mean speed of traffic measured in the field (S_{FM}), the observed flow rate for the period when the data was collected (V_f) and a heavy vehicle adjustment factor (f_{HV}, which is determined using HCM Equation 20-4 as above). An increase in both S_{FM} and V_f leads to a higher FFS, while an increase in f_{HV} serves to lower the FFS.

The indirect method, HCM Equation 2-2, is sensitive to the base free flow speed (BFFS, which must be estimated using speed data and local knowledge), a reduction factor for lane and shoulder width (f_{LS}), as well as for access points (f_A). As lane width and shoulder width increase, the FFS reduction factor (f_{LS}) decreases until you get to shoulders equal to or greater than 6 feet and lanes equal to or greater than 12 feet, at which point there is no reduction factor (HCM Exhibit 20-5). The adjustment factor for access points is based on HCM Exhibit 20-6 which shows that as the number of access points per mile increases there is a greater reduction in FFS, culminating in a f_{LS} of 10 mi/h when there are 40 or more access points per mile. Once you have the reduction factors for both lane and shoulder width and access points, you simply subtract them from the BFFS to arrive at the FFS in mi/h.

The final input needed in order to determine the ATS is the reduction factor for percentage of no-passing zones which is found using HCM Exhibit 20-11. The HCM notes that HCM Exhibit 20-11 shows that the effect of no-passing zones on average travel speed increases to a maximum of 4.5 mi/h at a two-way flow rate of 400 pc/h and then decreases at higher volumes. Once you have the three variables needed (FFS, v_p and f_{np}), you can then find the ATS using HCM Equation 20-5.

As one can see from the HCM Equation 20-5, average travel speed (ATS) decreases with a higher demand flow rate (V_p) and a higher percentage of no passing zones (f_{np}). Once the PTSF and the ATS are determined, it is then possible to determine the LOS for Class I highways by using HCM Exhibit 20-2.

It should be noted that the highway must meet the criteria for both the PTSF and ATS to be classified in any particular LOS. As the exhibit shows, as ATS is decreased and/or PTSF is increased, the LOS of the segment is lowered until LOS F is reached once either the ATS drops to 40 mi/h or lower or the PTSF rises to above 80 percent. Also, as the HCM notes, LOS F is also achieved whenever the flow rate exceeds the segment capacity.

APPENDIX C: NORTH CAROLINA LEVEL OF SERVICE (NCLOS) DEVELOPER'S GUIDE

Introduction

This document contains an overview of the information a developer will need to know in creating procedures, macros, or applications using the NCLOS calculations. NCLOS is an implementation of the 2000 Highway Capacity Manual produced by the Transportation Research Board. The calculations described in the 2000 HCM are implemented in the FacilityCalculator.dll component of NCLOS. This DLL externally accesses the HCM equations implemented by NCLOS. NCLOS does include an interface for the FacilityCalculator.dll. This interface is the FacilityAnalyzer.exe. Upon installation of NCLOS, both the FacilityAnalyzer.exe and the FacilityCalculator.dll are available to users and developers.

The first section**, 1. NCLOS Components**, describes the components of NCLOS in more detail, including a component diagram of the program. The second section titled **2. FacilityCalculator.dll Class Library** explains in considerable detail the classes that make up the FacilityCalculator.dll component. All of the classes described and the associated functions listed in the section can be accessed externally. The third section, **3. Input and Output Data,** details the data format required for an import file in order to process an entire project of Facilities simultaneously. The last section, **4. Integrating NCLOS into TransCAD,** gives an explanation (including an example) of how a developer could access the functionality of FacilityCalculator.dll from TransCAD.

1. NCLOS Components

NCLOS is broken up into two parts. The first part is the FacilityCalculator.dll and the second is the FacilityAnalyzer.exe. Figure C1 shows the components of the LOS Analysis program. This diagram displays the exposed interfaces that will be used by FacilityAnalyzer.exe. In addition, the FacilityCalculator.dll is a class library that can be used by any number of programs including TransCAD®.

FacilityAnalyzer.exe is a MS Windows® executable program containing the interface for NCLOS. This executable accesses FacilityCalculator.dll and is required to run NCLOS. FacilityAnalyzer.exe depends on FacilityCalulator.dll to calculate results as well as to store and retrieve data from the database.

The majority of this document focuses on FacilityCalculator.dll. FacilityCalculator.dll can be accessed by any number of applications other than FacilityAnalyzer.exe. Any development environment, including environments for macros and scripts which support OLE calls to DLL's, can be used to access

FacilityCalculator.exe. This DLL was designed specifically for use with TransCAD® by the NCDOT.

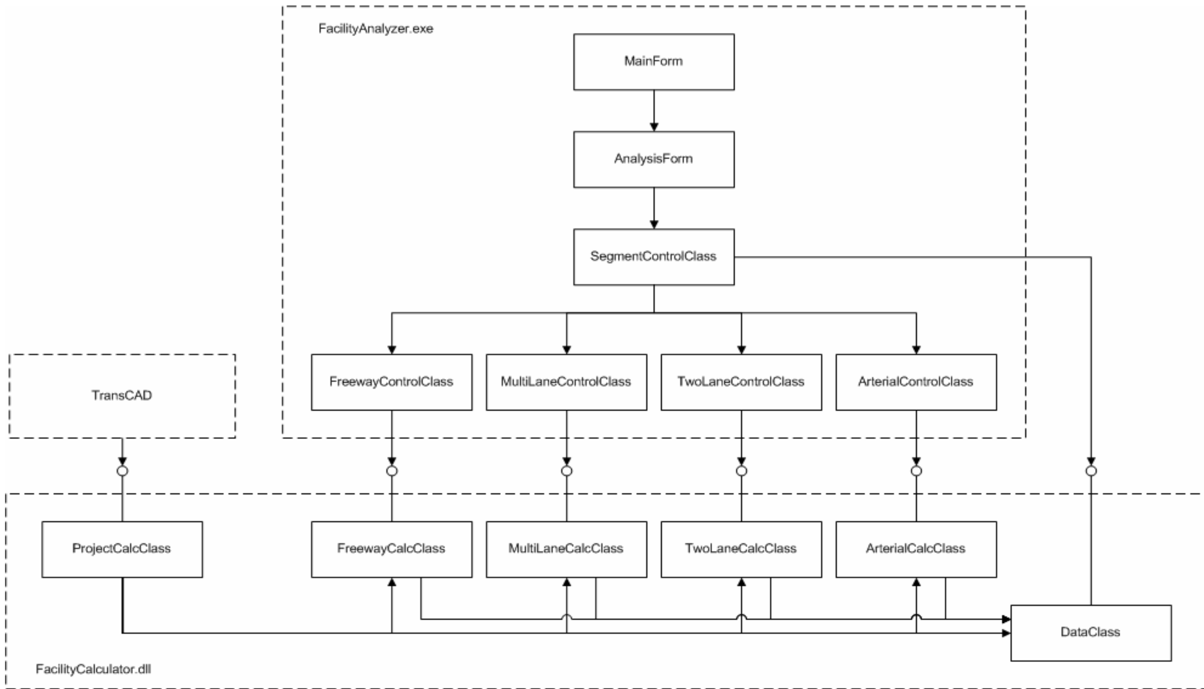


Figure C1. NCLOS Components

2. FacilityCalculator.dll Class Library

The classes provided in the class library FacilityCalculator.dll can be used to import data into and export results out of NCLOS. Using a flat file formatted as shown in Figure C2, entire projects can be moved simultaneously. The importing and exporting features are designed specifically for use with TransCAD® scripts. However, any windows application could access and utilize the classes provided in FacilityCalculator.dll.

All of the calculation classes and methods are available for use. The DataClass used for accessing the LOS database is also available. The names of the available classes and a description of the available classes are provided.

2.1. DataClass

The DataClass is the class used by FacilityAnalyzer.exe to access the data in the database. There are several different types of functions to access the different types of data. Many of these functions are only used by the FacilityAnalyzer.exe interface. However, there are a number of functions that may be used by external programs or scripts through the FacilityCalculator.dll. The two types of functions are project functions and segment data functions. A listing of each of the two function types and an explanation of each is provided. These functions enable an external user to manipulate the data in the NCLOS database directly without using the ProjectCalcClass. However, any developer should be aware that any modifications made through the DataClass will affect the data used in the interface as well. Many of the data checks are implemented by the interface. It is important for any developer to check data ranges and types as well as verify proper deletion and addition of projects and facility segments.

2.1.1. Project Functions

The project functions provide a mechanism for reading, adding, updating, and deleting project specific information.

2.1.1.1.GetNumProjects

The function declaration for GetNumProjects is listed. This function returns the number of projects currently stored in the NCLOS database.

```
Public Function GetNumProjects() As Integer
```

2.1.1.2.GetProjectByIndex

The function declaration for GetProjectByIndex is listed. This function returns the project information for a project given an index of the project in the NCLOS database table. By using the GetNumProjects function, the list of projects can be sequentially retrieved using this function.

```
Public Function GetProjectByIndex(ByVal nIndex As Integer, ByRef ID As Integer, ByRef Name As String, ByRef Manager As String, ByRef Organization As String, ByRef CreationDate As Date, ByRef Description As String) As Boolean
```

2.1.1.3.GetProjectByID

The function declaration for GetProjectByID is listed. This function returns the project information for a specific project given the NCLOS project ID of the project in the NCLOS database table. By first using the GetProjectByIndex function to determine a project ID, the information for a specific project can be retrieved using this function.

```
Public Function GetProjectByID(ByVal nID As Integer, ByRef Name As String, ByRef Manager As String, ByRef Organization As String, ByRef CreationDate As Date, ByRef Description As String) As Boolean
```

2.1.1.4.CreateProject

The function declaration for CreateProject is listed. This function creates a new project with blank data. The function returns the project ID of the new function. After using this function the UpdateProject function must be called to set the project data.

```
Public Function CreateProject() As Integer
```

2.1.1.5.UpdateProject

The function declaration for UpdateProject is listed. This function updates all of the project information for a specific project given the project ID. The project ID could be acquired by either the CreateProject or the GetProjectByIndex function.

```
Public Function UpdateProject(ByVal nID As Integer, ByVal Name As String, ByVal Manager As String,
ByVal Organization As String, ByVal Description As String) As Boolean
```

2.1.1.6.DeleteProject

The function declaration for DeleteProject is listed. The function deletes a specific project from the database given the project ID. This function will not prompt before deletion. Any developer using this function should be careful when using this function. If a project is deleted from the NCLOS database the project information as well as any facility segments in the project will be deleted as well. This information would only be recoverable if a backup copy of the Access database had been made.

```
Public Function DeleteProject(ByVal nID As Integer)
```

2.1.2. Segment Data Function

The segment data functions are used to create, delete, read, and update segments stored in the NCLOS database.

2.1.2.1.OpenFilteredSegmentData

The function declaration for OpenFilteredSegmentData is listed. This function filters a list of segments in the database given a project ID, segment type ID, region type ID, category 1 ID, and category 2 ID. If the ID's are anything other than 0 then only segments having the given ID's will be queried. If all the ID's are 0 then all of the segments in the database will be returned. Once a list of segments is opened using this function, the other segment data functions can then be executed. However, a list must be generated with this function before the other segment data functions will execute properly.

```
Public Function OpenFilteredSegmentData(ByVal P_ID As Integer, ByVal ST_ID As Integer, ByVal RT_ID As Integer, ByVal T1_ID As Integer, ByVal T2_ID As Integer) As Boolean
```

2.1.2.2.GetNumSegments

The function declaration for GetNumSegments is listed. This function returns the number of segments contained in the filtered list generated by OpenFilteredSegmentData. If a list has not been initialized or there is an error then the function returns 0.

```
Public Function GetNumSegments() As Integer
```

2.1.2.3.GetSegmentByID

The function declaration for GetSegmentByID is listed. This function retrieves a specific segment from the filtered segment list generated by OpenFilteredSegmentData. Given a segment ID the category information and segment name is returned. To get the parameters for a particular segment use either the GetFreewaySegmentByID, GetMultiLaneSegmentByID, GetTwoLaneSegmentByID, or GetArterialSegmentByID functions.

```
Public Function GetSegmentByID(ByVal nID As Integer, ByRef P_ID As Integer, ByRef ST_ID As Integer, ByRef RT_ID As Integer, ByRef T1_ID As Integer, ByRef T2_ID As Integer, ByRef Name As String, ByRef TC_ID As Integer) As Boolean
```

2.1.2.4.GetSegmentByIndex

The function declaration for GetSegmentByIndex is listed. This function retrieves a segment from the filtered segment list, generated by OpenFilteredSegmentData. Given an index of a segment the category information and segment name is returned. To get the parameters for a particular segment use either the GetFreewaySegmentByID, GetMultiLaneSegmentByID, GetTwoLaneSegmentByID, or GetArterialSegmentByID functions.

```
Public Function GetSegmentByIndex(ByVal nIndex As Integer, ByRef S_ID As Integer, ByRef P_ID As Integer, ByRef ST_ID As Integer, ByRef RT_ID As Integer, ByRef T1_ID As Integer, ByRef T2_ID As Integer, ByRef Name As String, ByRef TC_ID As Integer) As Boolean
```

2.1.2.5.CreateSegment

The function declaration for CreateSegment is listed. This function creates a new segment in a given project. The function requires all of the category information to generate the new segment. This function returns the segment ID of the newly created segment.

```
Public Function CreateSegment(ByVal nName As String, ByVal P_ID As Integer, ByVal ST_ID As Integer, ByVal RT_ID As Integer, ByVal T1_ID As Integer, ByVal T2_ID As Integer, ByVal TC_ID As Integer) As Integer
```

2.1.2.6.DeleteSegment

The function declaration for DeleteSegment is listed. This function deletes a segment from the filtered segment list generated by OpenFilteredSegmentData. If this function is successful the segment will be deleted and non-retrievable. Special consideration should be taken when calling this function because the verification is handled from the NCLOS interface and this function will not prompt a user. The return value is true if successful.

```
Public Function DeleteSegment(ByVal nIndex As Integer) As Boolean
```

2.1.2.7.Freeway Segment Data Functions

2.1.2.7.1. GetFreewaySegmentByID

The function declaration for GetFreewaySegmentByID is listed. This function returns a freeway segment given the ID of the segment. The segment ID can be found using the GetSegmentByIndex function.

```
Public Function GetFreewaySegmentByID(ByVal nID As Integer, ByRef Name As String, ByRef DriverPopulation As Single, ByRef TruckBusPercent As Single, ByRef RVPercent As Single, ByRef InterchangesPerMile As Single, ByRef GradePercent As Single, ByRef GradeLength As Single, ByRef LaneWidth As Integer, ByRef LatClearance As Integer, ByRef NumLanes As Integer, ByRef PHF As Single, ByRef K As Single, ByRef D As Single, ByRef MaxA As Integer, ByRef MaxB As Integer, ByRef MaxC As Integer, ByRef MaxD As Integer, ByRef MaxE As Integer) As Boolean
```

2.1.2.7.2. UpdateFreewaySegment

The function declaration for UpdateFreewaySegment is listed. This function updates the information stored in the NCLOS database for the freeway segment specified by nID. The nID is the segment ID of a freeway segment.

```
Public Function UpdateFreewaySegment(ByVal nID As Integer, ByVal Name As String, ByVal DriverPopulation As Single, ByVal TruckBusPercent As Single, ByVal RVPercent As Single, ByVal InterchangesPerMile As Single, ByVal GradePercent As Single, ByVal GradeLength As Single, ByVal LaneWidth As Integer, ByVal LatClearance As Integer, ByVal NumLanes As Integer, ByVal PHF As Single, ByVal K As Single, ByVal D As Single, ByVal MaxA As Integer, ByVal MaxB As Integer, ByVal MaxC As Integer, ByVal MaxD As Integer, ByVal MaxE As Integer) As Boolean
```

2.1.2.8. Multi-Lane Highway Segment Data Functions

2.1.2.8.1. GetMultiLaneSegmentByID

The function declaration for GetMultiLaneSegmentByID is listed. This function returns a multilane segment given the ID of the segment. The segment ID can be found using the GetSegmentByIndex function.

```
Public Function GetMultiLaneSegmentByID(ByVal nID As Integer, ByRef Name As String, ByRef DriverPopulation As Single, ByRef TruckBusPercent As Single, ByRef RVPercent As Single, ByRef AccessPointsPerMile As Single, ByRef GradePercent As Single, ByRef GradeLength As Single, ByRef LaneWidth As Integer, ByRef LatClearance As Integer, ByRef NumLanes As Integer, ByRef MedianType As String, ByRef PHF As Single, ByRef K As Single, ByRef D As Single, ByRef MaxA As Integer, ByRef MaxB As Integer, ByRef MaxC As Integer, ByRef MaxD As Integer, ByRef MaxE As Integer) As Boolean
```

2.1.2.8.2. UpdateMultiLaneSegment

The function declaration for UpdateMultiLaneSegment is listed. This function updates the information stored in the NCLOS database for the multilane segment specified by nID. The nID is the segment ID of a multilane segment.

```
Public Function UpdateMultiLaneSegment(ByVal nID As Integer, ByVal Name As String, ByVal DriverPopulation As Single, ByVal TruckBusPercent As Single, ByVal RVPercent As Single, ByVal AccessPointsPerMile As Single, ByVal GradePercent As Single, ByVal GradeLength As Single, ByVal LaneWidth As Integer, ByVal LatClearance As Integer, ByVal NumLanes As Integer, ByRef MedianType As String, ByVal PHF As Single, ByVal K As Single, ByVal D As Single, ByVal MaxA As Integer, ByVal MaxB As Integer, ByVal MaxC As Integer, ByVal MaxD As Integer, ByVal MaxE As Integer) As Boolean
```

2.1.2.9.Two Lane Highway Segment Data Functions

2.1.2.9.1. GetTwoLaneSegmentByID

The function declaration for GetTwoLaneSegmentByID is listed. This function returns a two lane segment given the ID of the segment. The segment ID can be found using the GetSegmentByIndex function.

```
Public Function GetTwoLaneSegmentByID(ByVal nID As Integer, ByRef Name As String, ByRef TwoLaneClass As String, ByRef TruckBusPercent As Single, ByRef RVPercent As Single, ByRef NoPassingZonesPercent As Single, ByRef AccessPointsPerMile As Single, ByRef GradePercent As Single, ByRef GradeLength As Single, ByRef LaneWidth As Integer, ByRef LatClearance As Integer, ByRef BFFS As Integer, ByRef PHF As Single, ByRef K As Single, ByRef D As Single, ByRef MaxA As Integer, ByRef MaxB As Integer, ByRef MaxC As Integer, ByRef MaxD As Integer, ByRef MaxE As Integer) As Boolean
```

2.1.2.9.2. UpdateTwoLaneSegment

The function declaration for UpdateTwoLaneSegment is listed. This function updates the information stored in the NCLOS database for the two lane segment specified by nID. The nID is the segment ID of a two lane segment.

```
Public Function UpdateTwoLaneSegment(ByVal nID As Integer, ByVal Name As String, ByVal TwoLaneClass As String, ByVal TruckBusPercent As Single, ByVal RVPercent As Single, ByVal NoPassingZonesPercent As Single, ByVal AccessPointsPerMile As Single, ByVal GradePercent As Single, ByVal GradeLength As Single, ByVal LaneWidth As Integer, ByVal LatClearance As Integer, ByVal BFFS As Integer, ByVal PHF As Single, ByVal K As Single, ByVal D As Single, ByVal MaxA As Integer, ByVal MaxB As Integer, ByVal MaxC As Integer, ByVal MaxD As Integer, ByVal MaxE As Integer) As Boolean
```

2.1.2.10. Arterial Segment Data Functions

2.1.2.10.1. GetArterialSegmentByID

The function declaration for GetArterialSegmentByID is listed. This function returns an arterial segment given the ID of the segment. The segment ID can be found using the GetSegmentByIndex function.

```
Public Function GetArterialSegmentByID(ByVal nID As Integer, ByRef Name As String, ByRef AS_StreetClassID As Integer, ByRef AS_FFSID As Integer, ByRef AS_ArivalTypeID As Integer, ByRef AS_CycleLength As Integer, ByRef AS_GCRatio As Single, ByRef AS_SignalsPerMile As Single, ByRef AS_Length As Single, ByRef AS_Plt As Single, ByRef AS_NumLanes As Integer, ByRef AS_K As Single, ByRef AS_PHF As Single, ByRef AS_D As Single, ByRef MaxA As Integer, ByRef MaxB As Integer, ByRef MaxC As Integer, ByRef MaxD As Integer, ByRef MaxE As Integer) As Boolean
```

2.1.2.10.2. UpdateArterialSegment

The function declaration for UpdateArterialSegment is listed. This function updates the information stored in the NCLOS database for the arterial segment specified by nID. The nID is the segment ID of an arterial segment.

```
Public Function UpdateArterialSegment(ByVal nID As Integer, ByRef Name As String, ByVal AS_StreetClassID As Integer, ByVal AS_FFSID As Integer, ByVal AS_ArivalTypeID As Integer, ByVal AS_CycleLength As Integer, ByVal AS_GCRatio As Single, ByVal AS_SignalsPerMile As Single, ByVal AS_Length As Single, ByVal AS_Plt As Single, ByVal AS_NumLanes As Integer, ByVal AS_K As Single, ByVal AS_PHF As Single, ByVal AS_D As Single, ByVal MaxA As Integer, ByVal MaxB As Integer, ByVal MaxC As Integer, ByVal MaxD As Integer, ByVal MaxE As Integer) As Boolean
```

2.2. ProjectCalcClass

The ProjectCalcClass provides the functionality to import, calculate, and export an entire project at one time. This class is all that should be necessary to interface NCLOS with TransCAD®. The functions of the ProjectCalcClass use the file format described in Section 4. Input and Output Data. The ProjectCalcClass has six public functions. A listing of the public functions of ProjectCalcClass and their descriptions are listed below.

2.2.1. ImportDataFile

The ImportDataFile function declaration is shown. This function has two required parameters and three optional parameters. This function takes a file formatted as specified in Section 4. Input and Output Data. The file is imported and stored in the NCLOS database. In order to calculate a project and export a project it must exist in the database. One may calculate and export a project without first calling this function, however, one must be sure the project does exist. This function returns the ProjectID. The ID is used to uniquely identify the project once imported into the database.

```
Public Function ImportDataFile(ByVal FilePath As String, ByVal ProjectName As String, Optional ByVal ProjectManager As String = "", Optional ByVal ProjectOrganization As String = "", Optional ByVal ProjectDescription As String = "") As Integer
```

FilePath – This variable should hold the directory path and file name of the input file containing the facilities and the characteristics as described in Section 4. Input and Output Data. This is a required variable.

ProjectName – This variable should be a string representation of a unique name assigned to the project. It is a required variable, and it is used later to identify the project.

ProjectManager – This is an optional variable. It should be a string representation of the project manager for the project being imported. This field is offered to supply additional information on the project.

ProjectOrganization – This is an optional variable. It should be a string representation of the project organization for the project being imported. This field is offered to supply additional information on the project.

ProjectDescription – This is an optional variable. It should be a string representation of a project description for the project being imported. This field is offered to supply additional information on the project.

2.2.2. CalculateProject

The CalculateProject function declaration is shown. There are two CalculateProject functions. Each one takes one variable. This function calculates all of the facilities in a project that exist in the NCLOS database. This function assumes that the project to be calculated exists in the database.

```
Public Sub CalculateProject(ByVal ProjectName As String)

Public Sub CalculateProject(ByVal ProjectID As Integer)
```

ProjectName – This variable is the unique name used to identify an existing project in the NCLOS database. It is a required variable.

ProjectID – This variable is the unique ID used to identify a project in the database. This ID is the same ID that is returned by the ImportDataFile function described in Section 3.2.1.

2.2.3. ExportDataFile

The ExportDataFile function declaration is shown. There are two ExportDataFile functions. Each one takes two variables. This function exports all of a project's facilities into a single output file. The file format is described in Section 4. Input and Output Data. This function assumes that the project to be exported exists in the database.

```
Public Sub ExportDataFile(ByVal ProjectName As String, ByVal FilePath As String)

Public Sub ExportDataFile(ByVal ProjectID As Integer, ByVal FilePath As String)
```

ProjectName – This variable is a string representation of the unique name used to identify a project in the database. This is a required variable.

ProjectID – This variable is the unique ID of a project in the database. This is a required variable.

FilePath – This variable is the directory path and file name where the export file is to be written. This must be a valid directory path. It is a required variable.

2.2.4. ExportFacility

The ExportFacility function declaration is shown. There are two ExportFacility functions. This function exports a single facility out of a project's facilities into a single out put file. The file format is described in Section 4. Input and Output Data. This function assumes that the project and the facility exist in the database.

```
Public Sub ExportFacility(ByVal SegmentName As String, ByVal P_ID As Integer, ByVal FilePath As String)

Public Sub ExportFacility(ByVal S_ID As Integer, ByVal FilePath As String)
```

SegmentName – This variable is the unique name given to a segment within a project. It is a required variable.

P_ID – This variable is the unique project ID which the requested facility is expected to exist in. It is a required variable.

S_ID – This variable is the unique facility ID to be exported. This is a required variable.

FilePath – This variable is the directory path and file name where the export file is to be written. This must be a valid directory path. It is a required variable.

2.3. FreewayCalcClass

The FreewayCalcClass handles the calculation on the input parameters necessary to find the appropriate AADT for given LOS ranges. Information regarding the public functions are listed. All of the parameters for a freeway must be set before the functions can be called. A list of the FreewayCalcClass's public parameters is given bellow.

```
'Public data members of FreewayCalcClass
Public TargetLOS As String
Public GradeType As String
Public AreaType As String
Public GradePrcnt As Single
Public GradeLength As Single
Public NumLanes As Integer
Public LaneWidth As Integer
Public LatClearance As Integer
Public InterchangeDensity As Single
Public DriverPopulation As Single
Public PrcntTrucksBusses As Single
Public PrcntRVs As Single
Public PHF As Single
Public K As Single
Public D As Single

'Public Constants used in calculations
Public Const GREATER = 0
Public Const LESS_EQUAL = 1
```

2.3.1. MaxAADT

The function declaration for MaxAADT is shown. This function or property returns the Maximum AADT possible for the given set of facility parameters and the desired LOS set in the FreewayCalcClass's parameter TargetLOS.

```
Public ReadOnly Property MaxAADT() As Long
```

2.3.2. MinAADT

The function declaration for MinAADT is shown. This function or property returns the Minimum AADT possible for the given set of facility parameters and the desired LOS set in the FreewayCalcClass's parameter TargetLOS.

```
Public ReadOnly Property MinAADT() As Long
```

2.3.3. Capacity

The function declaration for Capacity is shown. This function or property returns the Capacity AADT for the given set of facility parameters and the desired LOS set in the FreewayCalcClass's parameter TargetLOS. The capacity is the maximum AADT at the upper end of the LOS E range.

```
Public ReadOnly Property Capacity() As Long
```

2.3.4. VehiclesToPc

The function declaration for VehiclesToPc is shown. This function gives the number of vehicles in AADT and, using the truck, bus, and RV percentages, converts the raw AADT to passenger cars.

```
Public Function VehiclesToPc(ByVal nAADT As Long) As Long
```

2.3.5. GetTargetAADT

The function declaration for GetTargetAADT is shown. This function will return the AADT for a given traffic density. The nFindType parameter is one of the Greater or LESS_EQUAL constants defined in the class. If the GREATER constant is used, then the AADT returned will be one AADT higher than what is actually equal to the given density, where the AADT is rounded up. If LESS_EQUAL is used, then the returned AADT will be either less than or equal to the AADT that corresponds to the given density, where the AADT is rounded down.

```
Public Function GetTargetAADT(ByVal nDensity As Long, ByVal nFindType
As Long) As Long
```

2.3.6. GetDensity

The function declaration for GetDensity is shown. This function will return the traffic density for the given AADT and the parameters set in the class.

```
Public Function GetDensity(ByVal nAADT As Integer) As Single
```

2.4. MultiLaneCalcClass

The MultiLaneCalcClass handles the calculation on the input parameters necessary to find the appropriate AADT for given LOS ranges. Information regarding the public functions are listed. All of the parameters for a multi lane segment must be set before the functions can be called. A list of the MultiLaneCalcClass's public parameters is given below.

```
'Public data members of MultiLaneCalcClass
Public TargetLOS As String
Public GradeType As String
Public AreaType As String
Public GradePrcnt As Single
Public GradeLength As Single
Public NumLanes As Integer
Public MedianType As String
Public LaneWidth As Integer
Public LatClearance As Integer
Public AccessPoints As Single
Public DriverPopulation As Single
Public PrcntTrucksBusses As Single
Public PrcntRVs As Single
Public PHF As Single
Public K As Single
Public D As Single

'Private Constants used in calculations
Public Const GREATER = 0
Public Const LESS_EQUAL
```

2.4.1. InterpolateDensity

The function declaration for InterpolateDensity is shown. This function determines the density at capacity by calculating the FFS based on the parameters given. Based on the 2000 HCM equations, the density at capacity for a multilane segment is dependent on the FFS of that segment.

```
Public Function InterpolateDensity() As Integer
```

2.4.2. MaxAADT

The function declaration for MaxAADT is shown. This function or property returns the Maximum AADT possible for the given set of facility parameters and the desired LOS set in the MultiLaneCalcClass's parameter TargetLOS.

```
Public ReadOnly Property MaxAADT() As Long
```

2.4.3. MinAADT

The function declaration for MinAADT is shown. This function or property returns the Minimum AADT possible for the given set of facility parameters and the desired LOS set in the MultiLaneCalcClass's parameter TargetLOS.

```
Public ReadOnly Property MinAADT() As Long
```

2.4.4. Capacity

The function declaration for Capacity is shown. This function or property returns the Capacity AADT for the given set of facility parameters and the desired LOS set in the MultiLaneCalcClass's parameter TargetLOS. The capacity is the maximum AADT at the upper end of the LOS E range.

```
Public ReadOnly Property Capacity() As Long
```

2.4.5. VehiclesToPc

The function declaration for VehiclesToPc is shown. This function gives the number of vehicles in AADT and, using the truck, bus, and RV percentages, converts the raw AADT to passenger cars.

```
Public Function VehiclesToPc(ByVal nAADT As Long) As Long
```

2.4.6. GetTargetAADT

The function declaration for GetTargetAADT is shown. This function will return the AADT for a given traffic density. The nFindType parameter is one of the Greater or LESS_EQUAL constants defined in the class. If the GREATER constant is used, then the AADT returned will be one AADT higher than what is actually equal to the given density, where the AADT is rounded up. If LESS_EQUAL is used, then the returned AADT will be either less than or equal to the AADT that corresponds to the given density, where the AADT is rounded down.

```
Public Function GetTargetAADT(ByVal nDensity As Long, ByVal nFindType
As Long) As Long
```

2.4.7. GetDensity

The function declaration for GetDensity is shown. This function will return the traffic density for the given AADT and the parameters set in the class.

```
Public Function GetDensity(ByVal nAADT As Integer) As Single
```

2.5. TwoLaneCalcClass

The TwoLaneCalcClass handles the calculation on the input parameters necessary to find the appropriate AADT for given LOS ranges. Information regarding the public functions are listed. All of the parameters for a two lane segment must be set before the functions can be called. A list of the TwoLaneCalcClass's public parameters is given bellow.

```
'Public data members of TwoLaneCalcClass
Public TargetLOS As String
Public GradeType As Integer
Public AreaType As String
Public GradePrcnt As Single
Public GradeLength As Single
Public TwoLaneClass As String
Public MedianType As String
Public LaneWidth As Integer
Public LatClearance As Integer
Public AccessPoints As Single
Public BFFS As Integer
Public PrcntTrucksBusses As Single
Public PrcntRVs As Single
Public PrcntNoPassingZones As Single
Public PHF As Single
Public K As Single
Public D As Single

'Private Constants used in calculations
Public Const GREATER = 0
Public Const LESS_EQUAL = 1
```

2.5.1. MaxAADT

The function declaration for MaxAADT is shown. This function or property returns the Maximum AADT possible for the given set of facility parameters and the desired LOS set in the TwoLaneCalcClass's parameter TargetLOS.

```
Public Function MaxAADT(ByRef ATSControl As Boolean, ByRef PTSFMaxAADT
As Integer, ByRef ATSMaxAADT As Integer) As Long
```

2.5.2. MinAADT

The function declaration for MinAADT is shown. This function or property returns the Minimum AADT possible for the given set of facility parameters and the desired LOS set in the TwoLaneCalcClass's parameter TargetLOS.

```
Public Function MinAADT(ByRef ATSControl As Boolean, ByRef PTSFMaxAADT
As Integer, ByRef ATSMaxAADT As Integer) As Long
```

2.5.3. Capacity

The function declaration for Capacity is shown. This function or property returns the Capacity AADT for the given set of facility parameters and the desired LOS set in the TwoLaneCalcClass's parameter TargetLOS. The capacity is the maximum AADT at the upper end of the LOS E range.

```
Public Function Capacity(ByRef ATSControl As Boolean, ByRef PTSFAADT As
Integer, ByRef ATSAADT As Integer) As Long
```

2.5.4. VehiclesToPc

The function declaration for VehiclesToPc is shown. This function gives the number of vehicles in AADT and, using the truck, bus, and RV percentages, converts the raw AADT to passenger cars.

```
Public Function VehiclesToPc(ByVal nAADT As Long, ByVal ATSControl As
Boolean) As Long
```

2.5.5. GetATSCapacityAADT

The function declaration for GetATSCapacityAADT is shown. This function or property returns the Capacity AADT, as calculated for ATS (average travel speed), for the given set of facility parameters. The capacity is the maximum AADT at the upper end of the LOS E range.

```
Public Function GetATSCapacityAADT() As Long
```

2.5.6. GetPTSFCapacityAADT

The function declaration for GetPTSFCapacityAADT is shown. This function or property returns the Capacity AADT, as calculated for PTSF (percent time spent following), for the given set of facility parameters. The capacity is the maximum AADT at the upper end of the LOS E range.

```
Public Function GetPTSFCapacityAADT() As Long
```

2.5.7. GetPTSFTargetAADT

The function declaration for GetPTSFTargetAADT is shown. This function will return the AADT for a given PTSD. The nFindType parameter is one of the Greater or LESS_EQUAL constants defined in the class. If the GREATER constant is used, then the AADT returned will be one AADT higher than what is actually equal to the given density, where the AADT is rounded up. If LESS_EQUAL is used, then the returned AADT will be either less than or equal to the AADT that corresponds to the given density, where the AADT is rounded down.

```
Public Function GetPTSFTargetAADT(ByVal nPTSF As Single, ByVal
nFindType As Long) As Long
```

2.5.8. GetATSTargetAADT

The function declaration for GetATSTargetAADT is shown. This function will return the AADT for a given ATS. The nFindType parameter is one of the Greater or LESS_EQUAL constants defined in the class. If the GREATER constant is used, then the AADT returned will be one AADT higher than what is actually equal to the given density, where the AADT is rounded up. If LESS_EQUAL is used, then the returned AADT will be either less than or equal to the AADT that corresponds to the given density, where the AADT is rounded down.

```
Public Function GetATSTargetAADT(ByVal nATS As Single, ByVal nFindType
As Long) As Long
```

2.5.9. GetPTSF

The function declaration for GetPTSF is shown. This function will return the PTSF for the given AADT and the parameters set in the class.

```
Public Function GetPTSF(ByVal nAADT As Integer) As Single
```

2.5.10. GetATS

The function declaration for GetATS is shown. This function will return the ATS for the given AADT and the parameters set in the class.

```
Public Function GetATS(ByVal nAADT As Integer) As Single
```

2.6. ArterialCalcClass

The ArterialCalcClass handles the calculation on the input parameters necessary to find the appropriate AADT for given LOS ranges. Information regarding the public functions are listed. All of the parameters for an arterial segment must be set before the functions can be called. A list of the ArterialCalcClass's public parameters is given bellow.

```
Public FFSID As Integer
Public K As Single
Public D As Single
Public Plt As Single
Public StreetClassID As Integer
Public ArivalTypeID As Integer
Public CycleLength As Single
Public GCRatio As Single
Public Nolan's As Integer
Public Length As Single
Public SignalsPerMile As Single
Public PHF As Single
Public NumSegments As Integer
```

2.6.1. FindAADT

The function declaration for FindAADT is shown. This function determines the AADT based on the Sa (average travel speed through all segments) given and the public parameters already set.

```
Public Function FindAADT(ByVal nSa As Single) As Integer
```

2.6.2. FindSa

The function declaration for FindSa is shown. This function returns the Sa associated with the given AADT for the public parameters already set.

```
Public Function FindSa(ByVal AADT As Integer) As Single
```

3. Input and Output Data

The ProjectCalcClass is designed to read in a data file with a standard format. The data file format is shown in Figure C2. The output file created by the ProjectCalcClass has this identical format. The file format used by the ProjectCalcClass is the same as the file format output by the FacilityAnalyzer.dll export functionality.

The file must be a comma delimited text file. In the actual file the first row would be the headers. The color codes at the top are used to show which columns are used for which facility types. If a specific facility type does not use a specific column than FacilityCalculator.dll ignores that column. However, that column must still be included in the file—meaning a space for it is allotted but the field is left blank. More information on the columns and color codes can be found in the notes under the figure.

FacilityCalculator.dll expects to receive the first six (6) columns. The values after that are optional. If a value is not given, meaning it is left blank, then the default values for that column are used. The default values are set in the NCLOS database. In the output file all of the values that are needed for a specific facility type are given. If a default value was used on input, then the default value used will be given on output. For a list of acceptable values for each of the inputs see the 2000 Highway Capacity Manual. Below are the acceptable values for the NCLOS specific information required in the input file.

Street Name – This column is any valid string that must be unique for the given project.

TransCAD ID – This column is a TransCAD® specific ID. It is not used in NCLOS but it is used by TransCAD® to keep the facilities consistent. The TransCAD ID used in the input file will be the same as the TransCAD ID used in the export file for each facility.

SegmentID – In the input file this column is ignored. In the output file this ID will be filled in and will be unique for the given project. This is also the ID that can be used to reference any facility in the NCLOS database.

Region Type – This is a numerical identifier for the region type this facility is in. The possible values are:

1 – Coastal
2 – Piedmont
3 – Mountains

Facility Type – This is a numerical identifier for the facility type of the facility. The possible values are:

1 – Arterials
2 **–** Two-Lane Highways
3 – Multilane Highways
4 – Freeways

Type 1 Name – This is a string corresponding to the first category within each Facility Type.

Type 2 Name – This is a string corresponding to the second category within each Facility Type.

The string values of the Type 1 and Type 2 names are as listed below for each Facility Type. These values and the defaults used are the same as given in the Excel document NCLOS Defaults.

1 – Arterials:

- High-Speed
  - Principal Arterial
- Suburban
  - Principal Arterial
  - Minor Arterial
- Intermediate
  - Principal Arterial
  - Minor Arterial
- Urban
  - Principal Arterial
  - Minor Arterial

2 – Two-Lane Highways:

- Urban
  - Level
  - Rolling
  - Mountainous
  - Specific Grade
- Suburban
  - Level
  - Rolling
  - Mountainous
  - Specific Grade
- Rural
  - Level
  - Rolling
  - Mountainous
  - Specific Grade

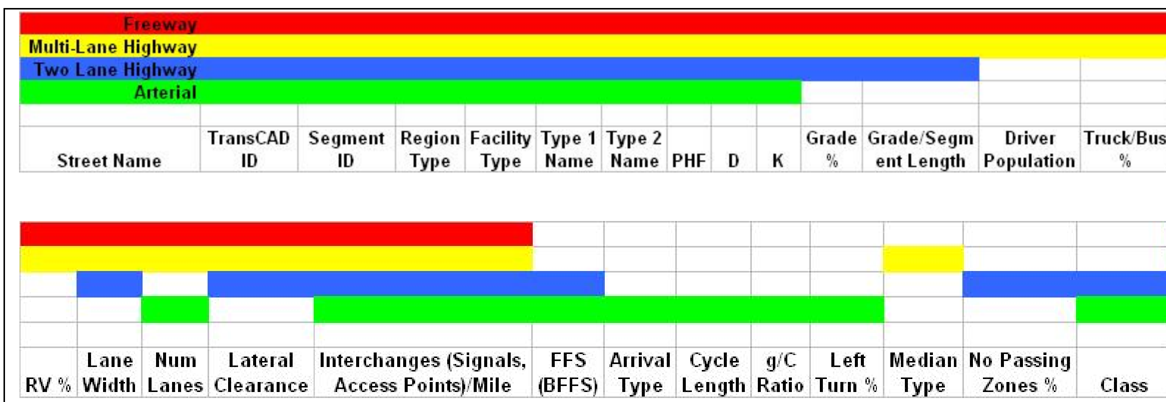
3 – Multilane Highways

- Urban
  - Level
  - Rolling
  - Mountainous
  - Specific Grade
- Suburban
  - Level
  - Rolling
  - Mountainous
  - Specific Grade

- Rural
    - Level
    - Rolling
    - Mountainous
    - Specific Grade

4 – Freeways

- Urban
    - Level
    - Rolling
    - Mountainous
    - Specific Grade
- Suburban
    - Level
    - Rolling
    - Mountainous
    - Specific Grade
- Rural
    - Level
    - Rolling
    - Mountainous
    - Specific Grade



*This figure is color coded to show which columns are used for each facility type. The colored bar extends through all of the columns across the top headings. Places where the color is left out indicate a heading that is not used for the given facility type. For an actual file the color codes would not be present and the headings would be the first row of a file.

**In some cases a column is used for two or more different yet similar values. For example the 'Interchanges (Signals, Access Points)/Mile' column is used for all four facility types. For freeways the column is used to hold the number of interchanges per mile. For multi-lane and two lane highways the column is used for signals per mile. For arterials the column is used for the number of access points per mile. While these numbers mean slightly different things they are conceptually the same. Alternative values are shown in parenthesis.

Figure C2. Import/Export File Format

4. Integrating NCLOS into TransCAD®

Integrating NCLOS FacilityCalculator.dll into a TransCAD® program is relatively easy. Figure C3 shows an example of how this can be accomplished.

```
Macro "CalculateProject"
  ProjectCalcObj = OLECreateObject("FacilityCalculator.ProjectCalcClass", )
  InputFileLoc = “C:/NCLOSFiles/ProjectInput.txt”
  ProjectName = “NewProject”
  OLECall(ProjectCalcObj, “ImportDataFile”, {InputFileLoc, ProjectName}, )
  OLECall(ProjectCalcObj, “CalculateProject”, {ProjectName}, )
  OutputFileLoc = “C:/NCLOSFiles/ProjectInput.txt”
  OLECall(ProjectCalcObj, “ExportDataFile”, {ProjectName, OutputFileLoc}, )
endMacro
```

Figure C3. TransCAD® Example

In the macro it is necessary to create an instance of the class you would like to use. ProjectCalcObj is created as an instance of the ProjectCalcClass class in the FacilityCalculator.dll. To do this the TransCAD® function OLECreateObject is called. One of the functions in the ProjectCalcClass is called CalculateProject. This function takes a string representation of project name as input. The example in Figure C3 sets a variable called ProjectName to the name of the project that was previously imported.

The TransCAD® OLECall function is used to execute the CalculateProject function. The OLECall function will take an instance of a class created with OLECreateObject and run the specified function with the given parameters. The first argument of OLECall is the class variable, in this case ProjectCalcObj. The second is a string to be the name of the function in ProjectCalcObj to execute; in this case that function is CalculateProject. The third parameter is the argument(s) to pass to the function. In this case there is only one argument called ProjectName. These arguments must appear in braces and if more than one argument is required there must be a comma separating each argument inside the braces.

To learn more about the class, function, or input file used in this example refer to the section **FacilityCalculator.dll Class Library** and **Input and Output Data**.