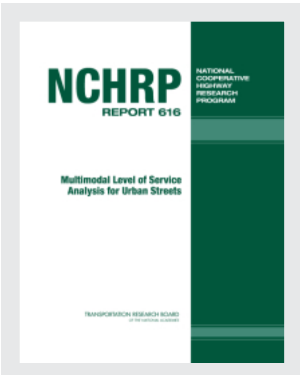

Multimodal Level of Service Analysis for Urban Streets

DETAILS

110 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-11742-5 | DOI 10.17226/14175

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 616

Multimodal Level of Service Analysis for Urban Streets

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Research sponsored by the American Association of State Highway and Transportation Officials
in cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2008
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 616

Project 3-70
ISSN 0077-5614
ISBN: 978-0-309-11742-5
Library of Congress Control Number 2008905870

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are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

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Printed in the United States of America

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FOREWORD

By Dianne Schwager
Staff Officer
Transportation Research Board

NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets will be of interest to public agencies responsible for the planning, design, and operation of urban streets. This report provides a method for assessing how well an urban street serves the needs of all of its users: auto drivers, transit passengers, bicycle riders, and pedestrians.

NCHRP Project 3-70 developed and calibrated a method for evaluating the multimodal level of service (MMLOS) provided by different urban street designs and operations. This MMLOS method is designed for evaluating "complete streets," context-sensitive design alternatives, and smart growth from the perspective of all users of the street. The analyst can use the MMLOS method to evaluate the tradeoffs of various street designs in terms of their effects on the auto driver's, transit passenger's, bicyclist's, and pedestrian's perceptions of the quality of service provided by the street.

The MMLOS method is described in the user's guide appendix to this final report (published as *NCHRP Web-Only Document 128*). It can be implemented in a simple spreadsheet.

The MMLOS method estimates the auto, bus, bicycle, and pedestrian level of service on an urban street using a combination of readily available data and data normally gathered by an agency to assess auto and transit level of service. The data requirements of the MMLOS method include geometric cross-section, signal timing, the posted speed limit, bus headways, traffic volumes, transit patronage, and pedestrian volumes.

The NCHRP Project 3-70 MMLOS method also enables agencies to balance the level of service needs of auto drivers, transit riders, bicycle riders, and pedestrians in their street designs by providing agencies with a tool for testing different allocations of scarce street right-of-way to the different modes using the street.

CONTENTS

AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 3-70 by Dowling Associates, Inc., Oakland, California.

Dr. Aimee Flannery of George Mason University and Dr. Nagui Rouphail of the Institute for Transportation Research and Education (ITRE) developed the recommended auto level of service model. Dr. Flannery developed the auto video clips and conducted the auto, bicycle, and pedestrian video laboratories around the United States. Dr. Flannery developed the linear and non-linear regression models and conducted the initial statistical analysis for the auto LOS models. Dr. Kathryn Wochinger assisted in the design of the video laboratory survey instruments and protocol.

Dr. Rouphail and Laureano Rangel led the statistical development of the ordered logistic auto LOS model.

Mr. Paul Ryus of Kittelson Associates developed the transit LOS model and conducted the Phase 1 transit data collection effort.

Mr. David Reinke of Dowling Associates led the Phase 2 transit data collection effort and performed various statistical analyses in support of the auto and transit model developments. Mr. Chris Ferrell of Dowling Associates updated the literature review.

Mr. Bruce Landis, Mr. Theo Petritsch, and Dr. Herman Huang of Sprinkle Consulting, Inc., developed the pedestrian and bicycle LOS models and performed the statistical analyses associated with that effort. They also shot the video clips for the bicycle and pedestrian portions of the video laboratories.

Mr. Mark Vandehey of Kittelson Associates and Dr. James Bonneson of Texas A & M coordinated the subject research with the ongoing NCHRP 3-79 project and provided Highway Capacity Committee perspectives on the research.

The authors would like to thank the management of Tri-Met (Portland, OR), Broward County Transit (Ft. Lauderdale, FL), Washington Metropolitan Area Transit Authority (Washington, DC), AC Transit (Oakland, CA) and Muni (San Francisco, CA) for their permission and support to conduct on-board transit surveys on selected routes.

SUMMARY

Multimodal Level of Service Analysis for Urban Streets

This report presents the results of a 2-year investigation into how users of urban streets perceive the multimodal quality of service provided by the streets, NCHRP Project 3-70, Multimodal Level of Service for Urban Streets.

A preliminary investigation was conducted to determine the key factors influencing travelers' perceptions of urban street level of service (LOS) from the perspective of auto drivers, bus riders, bicycle riders, and pedestrians. The results of this preliminary investigation were used to design a series of video laboratories (for auto, bicycle, and pedestrian modes) and field surveys (for the bus mode).

Video clips were shot of typical urban street segments in the United States from the perspective of auto drivers, bicycle riders, and pedestrians. Between 26 and 35 video clips were shot for each mode. These video clips were then shown to 145 people in four different urban areas of the United States. Survey participants were asked to rate the quality of service displayed in each video clip on a scale from A to F, with A being defined as Best and F being defined as Worst.

In the field, on-board surveys were conducted of 14 bus routes in four different metropolitan areas. A total of 2,678 bus passengers were surveyed about their perceptions of bus quality of service.

Four separate LOS models (one for each mode) were then fitted to the video laboratory and field survey data. All four LOS models are sensitive to the street design (e.g., number of lanes, widths, and landscaping), traffic control devices (signal timing, speed limits), and traffic volumes. The models incorporate directly and indirectly the interactions of the various users of the street. For example, improved signal timing increases auto speeds and bus speeds which increases auto and bus LOS. However, the higher auto and bus speeds adversely affect the level of service perceived by bicyclists and pedestrians.

The LOS models are ideal for evaluating the benefits of "complete streets" and "context-sensitive" design options because the models quantify the interactions of the modes sharing the same street right-of-way.

The models enable the analyst to test the tradeoffs of various allocations of the urban street cross section among autos, buses, bicycles, and pedestrians. For example, the analyst can test the effects of reducing a four-lane street to three lanes and using the width saved to provide bicycle lanes and a landscaped strip between the sidewalk and the street. The method enables the analyst to compute the before and after levels of service for auto, bus, bicycle, and pedestrians.

A User's Guide was written explaining the LOS models and their application. The User's Guide is written in the general format of a draft chapter for the *Highway Capacity Manual* to facilitate its potential incorporation into the next edition of the *Highway Capacity Manual*.

A spreadsheet software engine was written and delivered to assist analysts in applying the LOS methods.

The Final Report describes the development of the LOS models, while the User's Guide focuses on explaining the application of the models with detailed descriptions of each model and example applications.

CHAPTER 1

Introduction

In many urban areas throughout the United States, there is a desire to evaluate transportation services of roadways from a multimodal perspective. Improvements to non-automobile modes are often emphasized to achieve community goals such as "Smart Growth" and curbing urban sprawl. The Transportation Equity Act for the 21st Century (TEA-21) and its predecessor, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), call for mainstreaming transit, pedestrian, and bicycle projects into the planning, design, and operation of the U.S. transportation system. In addition to measuring the levels of service for automobile users, measuring the levels of service for transit, pedestrian, and bicycle users along U.S. roadways is also desired.

1.1 Research Objective and Scope

The objective of NCHRP Project 3-70 was to develop and test a framework and enhanced methods for determining levels of service for automobile, transit, bicycle, and pedestrian modes on urban streets, paying particular respect to the interaction among the modes.

The scope of the project was as follows:

- Urban streets were defined as arterials and major collectors.
- This research project was to address all vehicular and pedestrian movements along urban streets, including turning movements and pedestrian movements across urban streets.
- Transit (i.e., bus and rail) was initially defined as at-grade, scheduled, fixed-route services that operated within the roadway right-of-way. Other forms of transit services were allowed be addressed subsequently.
- The analysis techniques were not necessarily to be restricted to 1-hour or 15-minute analysis time frames (transit or pedestrian "micro-peaks").
- Safety and economic aspects were to be included only and insofar as they influenced the perceptions of LOS.
- The HCM lists nine conditions (p. 15-1) not accounted for in the current urban streets methodology:
  1. Presence or lack of on-street parking;
  2. Driveway density or access control;
  3. Lane additions leading up to or lane drops leading away from intersections;
  4. The impacts of grades between intersections;
  5. Any capacity constraints between intersections (such as a narrow bridge);
  6. Mid-block medians and two-way left turn lanes;
  7. Turning movements that exceed 20 percent of the total volume on the street;
  8. Queues at one intersection backing up to and interfering with the operation of an upstream intersection; and
  9. Cross-street congestion blocking through traffic.

  These limitations were not necessarily to be accepted in this project.

- Although this project was to address automobile LOS, revisions in operational techniques (e.g., calculation of average travel speed, mid-block running times, and control delay) for the automobile mode were not a significant part of this project.

1.2 The Research Plan

The research plan consisted of the following tasks:

0. Development of Amplified Work Plan
1. LOS Framework Revisions
2. Data Collection
3. Develop LOS Models
4. Interim Report
5. HCM Chapter
6. HCM Software
7. HCM Sample Problems

8. Final Report
9. HCQS Presentations

1.3 This Report

This Report presents the final recommended LOS models and draft Urban Streets chapter on urban street level of service for the 2010 *Highway Capacity Manual*. The report is organized as follows:

- Chapter1, Introduction. This chapter presents an overview of the research project and the organization of the report.
- Chapter 2, State Of The Practice. This chapter reviews the state of the practice for estimating the level of service for auto drivers, transit riders, bicycle riders, and pedestrians on urban streets. The *Highway Capacity Manual*, *Transit Capacity and Quality of Service Manual*, and the Florida DOT Quality/Level of Service Guide are reviewed.
- Chapter 3, Literature Review. This chapter presents an overview of recent literature in the field of modal level of service.
- Chapter 4, Data Collection. This chapter describes the selection of the data collection methods for this study and describes the video lab and field work used to obtain observations from the traveling public on their perceptions of level of service.
- Chapter 5, Auto LOS Model. This chapter presents the recommended LOS model for auto drivers along with an alternative model designed to address concerns raised by the Highway Capacity Committee. Validation data are provided illustrating the accuracy of the model.
- Chapter 6, Transit LOS Model. This chapter describes the recommended LOS model for transit passengers on an urban street. Validation data are provided illustrating the accuracy of the model.
- Chapter 7, Bicycle LOS Model. This chapter describes the recommended LOS models for bicycle riders on an urban street. Validation data are provided illustrating the accuracy of the model.
- Chapter 8, Pedestrian LOS Model. This chapter describes the recommended LOS models for pedestrians on an urban street. Validation data are provided illustrating the accuracy of the model.
- Chapter 9, Integrated Multimodal LOS Model Framework. This chapter explains how the four modal LOS models are integrated in that they share the same LOS rating system, share much of the same input data, and reflect intermodal effects of one mode on the perceived level of service of the other.
- Chapter 10, Accomplishment of Research Objectives. This chapter summarizes the accomplishment of the research objectives.
- Appendix A, Subject Data Collection Forms. This appendix provides copies of the video lab data collection forms.
- Appendix B, Study Protocol. This appendix describes the protocol used to collect LOS perceptions in the video labs.
- Appendix C, Example Recruitment Flyer/Poster. This appendix shows the flyer used to recruit participants in the video laboratories.

Appendix D, Draft Users Guide, which presents the draft users guide on urban street level of service, is available on line as *NCHRP Web-Only Document 128* at http://trb.org/news/blurb_detail?id=9186.

CHAPTER 2

State of the Practice

This chapter summarizes the state of the practice in the United States with regard to multimodal LOS analysis and identifies needed improvements. The review includes national and state guides on LOS analysis and profiles of typical and state-of-the-art applications of modal and multimodal LOS by public agencies in the United States.

2.1 State-of–the-Practice Survey

A brief state-of-the-practice survey was conducted of a few selected representative public agencies to determine how public agencies currently use level of service. Exhibit 1 lists the people and agencies contacted.

The state-of-the-practice survey identified three major professional manuals typically referenced by public agencies when computing multimodal highway level of service. These manuals are the *Highway Capacity Manual* [**1**], the *Transit Capacity and Quality of Service Manual* [**2**], and *Florida's Quality/Level of Service Handbook* [**3**]. The portions of these manuals relevant to the current research are summarized in the following subsections.

Highway Capacity Manual

The *Highway Capacity Manual* (HCM) provides LOS measures, thresholds, and estimation procedures for auto, transit, bicycle, and pedestrian modes.

Urban Street LOS

Chapter 15 of the HCM defines urban street LOS according to the mean speed of through traffic on an urban street. The precise thresholds vary by urban street class (see Exhibit 2), which affects the presumed mid-block free-flow speed on each street.

When one takes into account the differing typical free-flow speeds for the urban street classes, the speed breakpoint for LOS A averages about 85% of the typical mid-block free-flow speed, LOS B averages 67%, LOS C averages 51%, LOS D averages 39%, and LOS E averages 29%.

The HCM provides a methodology for estimating the mean speed for through traffic on an urban street. The methodology reduces the mid-block free-flow speed according to the average delay to through traffic at each traffic signal. This speed is further reduced to account for delays between signals due to short signal spacing (called "segment running time" in the HCM). The effects of signal progression are taken into account in the computation of mean delay at each signal.

For comparison with the other model forms discussed later, the HCM look-up table can be expressed (approximately) in the form of a linear function of facility type and speed, as follows:

$$\text{LOS} = \textit{Integer}\{0.151231 * \textit{Speed} + 0.636927 * \textit{Class} - 2.17765\} \quad \text{(Eq. 1)}$$

Where

LOS = HCM LOS Integer Scale (where A=5, F = 0)

Integer = The integer function (rounds off the value to the nearest integer value).

Speed = Mean speed of through traffic on arterial in mph.

Class = Arterial Class as defined by HCM (Class 1, 2, 3, or 4)

(R-Square = 0.97, all variables significant)

Transit LOS

Chapter 27 of the HCM provides four transit LOS measures, adapted from the six presented in the *Transit Capacity and Quality of Service Manual*, First Edition: Service Frequency, Hours of Service, Passenger Load, and Service Reliability. These measures are presented below under the *Transit Capacity and Quality of Service Manual* section.

Exhibit 1. Contacts for State of Practice Survey.

Contact	Agency	Location	Geographic US	Agency Type
1. Conan Cheung	MTDB	San Diego, CA	West	Transit Operator
2. Douglas Dalton	Wisconsin DOT	Milwaukee, WI	Central	DOT
3. Doug McLeod	Florida DOT	Tallahassee, FL	East	DOT
4. Juan Robles	Colorado DOT	Denver, CO	Mountain	DOT
5. James Okazaki	Los Angeles DOT	Los Angeles, CA	West	City
6. Carolyn Gonot	Santa Clara VTA	San Jose, CA	West	CMA/Transit
7. Jim Altenstadter	PIMA AG	Tucson, AZ	Mountain	MPO
8. John Halkias	FHWA	Washington, DC	East	Federal

Bicycle LOS

Chapter 19 of the HCM provides bicycle LOS criteria, thresholds, and estimation procedures for off-street paths and designated bicycle lanes on urban streets (summarized in Exhibit 3 and 4). It is based on research conducted for the FHWA [**4**].

The HCM provides procedures for estimating mean bicycle speed and mean control delay. The mean control delay is estimated based on the signal timing at each signal. The mean speed is estimated by reducing the presumed 15 mph bicycle free-flow speed by the delay at each signal.

For off-street bicycle/pedestrian paths, the HCM-adopted bicycle LOS criterion is based on the frequency of encounters (i.e. passing and meeting events) between bicyclists and pedestrians on the path. For two-way, two-lane paths, less than 40 encounters per hour is LOS A. More than 195 encounters per hour is LOS F. A procedure is provided for estimating the number of encounters based on pedestrian and bicycle volumes.

Pedestrian LOS

Chapter 18 of the HCM provides pedestrian LOS criteria, thresholds, and estimation procedures for sidewalks, street corners, crosswalks, and off-street paths. It is based on research conducted for the FHWA [**5**].

For sidewalks, the key service criterion is space per pedestrian (inverse of density) (see Exhibit 5). A procedure is provided for estimating this based on facility width and pedestrian volumes. These are based on observations from Fruin [**6**].

For shared bicycle and pedestrian paths, the pedestrian LOS is computed according to the expected number of bicycle-pedestrian encounters per hour (see Exhibit 6). The criteria and thresholds are based on research by Botma [**7**]. A procedure is provided for estimating this based on pedestrian and bicycle volumes.

At signalized intersections, the pedestrian LOS is measured using average delay to the pedestrians waiting to cross the streets (see Exhibit 7). A procedure is provided for estimating delay based on the pedestrian or vehicle signal timing.

Average crossing delay is also used to estimate pedestrian LOS for unsignalized intersections. The LOS thresholds are more conservative (less than 5 seconds of delay equals LOS A. More than 45 seconds of delay equals LOS F).

For urban streets with sidewalks, the HCM bases the pedestrian level of service on mean speed over the length of the street (see Exhibit 8). The average walking speed between intersections is reduced according to the average wait time at each intersection to arrive at a mean walking speed for the length of the urban street.

Transit Capacity and Quality of Service Manual

TCRP Report 100: Transit Capacity and Quality of Service Manual, 2nd Edition (TCQSM) presents a two-dimensional LOS framework. It is a matrix covering two service quality dimensions (i.e., Availability and Comfort & Convenience) for three transit system elements (i.e., Stops, Route Segments, and Systems) (see Exhibit 9). Each of the six cells of the matrix provides a service measure for which levels of service are

Exhibit 2. Urban Street Level of Service.

Urban Street Class	I	II	III	IV
Range of FFS	45-55 mph	35-45 mph	30-35 mph	25-35 mph
Typical FFS	50 mph	40 mph	35 mph	30 mph
LOS				
A	>42 mph	> 35 mph	>30 mph	>25 mph
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

FFS = mid-block free-flow speed of street. Exhibit adapted from Exhibit 15-2, *Highway Capacity Manual*

Exhibit 3. HCM Bicycle LOS for Bicycle Lanes on Urban Streets.

LOS	Average Bicycle Speed
A	> 14 mph
B	>9-14
C	>7-9
D	>5-7
E	≥4-5
F	<4

Adapted from Exhibit 19-5 of the *Highway Capacity Manual*.

Exhibit 4. HCM Bicycle LOS at Signals.

LOS	Average Control Delay
A	< 10 secs
B	≥10-20
C	>20-30
D	>30-40
E	>40-60
F	>60

Adapted from Exhibit 19-4 of the *Highway Capacity Manual*.

Exhibit 5. HCM Pedestrian LOS Criteria for Sidewalks.

LOS	Space/Pedestrian
A	>60 S.F.
B	>40-60
C	>24-40
D	>15-24
E	>8-15
F	≤8

S.F. = square feet. Adapted from Exhibit 18-3 of the *Highway Capacity Manual*

Exhibit 6. HCM Pedestrian LOS Criteria for Paths.

LOS	Encounters/hour
A	≤38
B	>38-60
C	>60-103
D	>103-144
E	>144-180
F	>180

Adapted from Exhibit 18-8 of the *Highway Capacity Manual*

Exhibit 7. HCM Pedestrian LOS at Signals.

LOS	Average Crossing Delay
A	< 10 secs
B	≥10-20
C	>20-30
D	>30-40
E	>40-60
F	>60

Adapted from Exhibit 18-9 of the *Highway Capacity Manual*.

Exhibit 8. HCM Pedestrian LOS for Urban Streets.

LOS	Mean Walking Speed
A	> 4.36 fps
B	>3.84-4.36
C	>3.28-3.84
D	>2.72-3.28
E	>1.90-2.72
F	< 1.90 fps

fps = feet per second. Adapted from Exhibit 18-14 of the Highway Capacity Manual.

developed; the TCQSM 1st Edition (*TCRP Web-Only Document 6*) also provided one or more other performance measures also thought to be important to consider. Lower-level measures (e.g., stop level) are also applicable at higher levels (i.e., the route segment or system levels).

The TCQSM distinguishes between demand-responsive transit and fixed-route transit service. The LOS criteria for fixed-route transit service are covered in this review.

Availability Measures of Level of Service

For transit stops the frequency of service is the LOS criterion (see Exhibit 10).

For transit route segments and corridors, the hours of service each day (i.e., the number of hours per day when service is available at least hourly) is the LOS criterion (see Exhibit 11). For route segments and corridors where stops are made, service frequency would also be evaluated at the individual stops (depending on routing and scheduling patterns, not all buses may stop at every stop).

At the system level, the service coverage area as a percentage of the transit supportive area is the LOS criterion. The transit supportive area is defined as the area with a minimum density of four jobs per gross acre or three dwellings per gross acre, based on work by Pushkarev and Zupan [**8**]. The transit service coverage area is that area

Exhibit 9. TCQSM Two-Dimensional LOS Framework.

LOS Dimension	Transit Stop	Route Segment	System
Availability	Frequency	Hours of Service	Coverage
Comfort & Convenience	Load Factor	Reliability	Time Differences

Adapted from Exhibit 3-1, *Transit Capacity and Quality of Service Manual*

Exhibit 10. TCQSM Service Frequency LOS.

LOS	Vehicles Per Hour
A	> 6
B	5 to 6
C	3 to 4
D	2
E	1
F	< 1

Adapted from Exhibit 27-1 of the *Highway Capacity Manual.*

Exhibit 11. TCQSM Hours of Service LOS.

LOS	Hours Per Day
A	19-24
B	17-18
C	14-16
D	12-13
E	4-11
F	0-3

Adapted from Exhibit 27-4 of the *Highway Capacity Manual.*

within the transit supportive area that lies within one-quarter air mile of a stop. Greater than 90% is LOS A. Less than 50% is LOS F.

Comfort & Convenience Measures of LOS

For transit stops, the TCQSM "comfort and convenience" measure of level of service is based on passenger load (see Exhibit 12). For typical bus services operating on urban streets, where most passengers would be seated, LOS A-C is based on the load factor (i.e., total number of passengers divided by the number of seats), while LOS D-F is based on the average area per person available for standees. This measure originated in the 1985 HCM.

For route segments and corridors, the comfort and convenience level of service measure is "on-time performance" and headway adherence. For scheduled service of fewer than six vehicles per hour, Exhibit 13 is used.

For scheduled service of six vehicles per hour or greater the reliability LOS is according to Exhibit 14.

Exhibit 12. TCQSM Passenger Load LOS for Bus.

LOS	Standing Passenger Area (ft^2/p)	Load Factor
A	>10.8	0.00-0.50
B	8.2-10.8	0.51-0.75
C	5.5-8.1	0.76-1.00
D	3.9-5.4	1.01-1.25
E	2.2-3.8	1.26-1.50
F	<2.2	>1.50

Adapted from Exhibit 3-26 of the TCQSM.

The on-time performance measure applies to all services with a published timetable, and its LOS thresholds are all in 5% increments, with the LOS E/F threshold set at 75%. The headway adherence measure now applies to all services scheduled to a headway or operating at headways of 10 minutes or less (thus, both measures could apply to some routes). The measure definition allows for variable headways during the peak hour, and the LOS thresholds correspond to the probability that no more than a certain percentage of transit vehicles would be more than one-half headway off schedule.

For the system level, the LOS criterion is door-to-door "travel time difference" between driving a car and taking transit. If transit takes 60 minutes longer than driving, it is LOS F for transit. If they are equal, or transit is faster, it is LOS A for transit.

In addition to the LOS measures presented in the Quality of Service section of the TCQSM, the Stop, Station, and Terminal Capacity section presents a series of pedestrian levels of service for elements of passenger facilities, such as walkways and stairways, based on work by Fruin (same reference as previous). These levels of service are presented more for design purposes (e.g., sizing a station element to provide a certain level of service) than for evaluating existing facilities. These levels of service are similar to, but have different thresholds

Exhibit 13. TCQSM Reliability LOS for Infrequent Urban Scheduled Transit Service.

LOS	On-Time Percentage
A	95.0-100.0%
B	90.0-94.9%
C	85.0-89.9%
D	80.0-84.9%
E	75.0-79.9%
F	<75%

Applies to scheduled service of fewer than six vehicles per hour.
Adapted from Exhibit 3-29 of the TCQSM.

Exhibit 14. TCQSM Reliability LOS for Frequent Urban Scheduled Transit Service.

LOS	Coefficient of Variation
A	0.00-0.21
B	0.22-0.30
C	0.31-0.39
D	0.40-0.52
E	0.53-0.74
F	≥0.75

Applies to scheduled service of six or more vehicles per hour.
The coefficient of variation is the ratio of the standard deviation of headway deviations divided by the mean scheduled headway. Headway deviations are measured as the actual headway minus the scheduled headway.
Adapted from Exhibit 3-30 of the TCQSM.

than, the HCM pedestrian measures, as the TCQSM measures are intended for transit facilities, while the HCM measures are intended for sidewalks. However, the TCQSM's pedestrian waiting area measure would be applicable to bus stops along arterial streets.

Florida Quality/Level of Service Handbook

The Florida Q/LOS Handbook provides LOS measures, thresholds, and estimation methodologies for auto, transit, bicycle, and pedestrian modes.

Auto LOS

The FDOT handbook uses the urban street LOS criteria and thresholds contained in the Urban Streets chapter of the *Highway Capacity Manual*. Various default values are provided for some of the more difficult to obtain input data.

Transit LOS

The transit level of service method and thresholds in the FDOT handbook are designed to be applied only to fixed-route, fixed-schedule bus service. The bus LOS thresholds are keyed to the adjusted service frequency (see Exhibit 15). The actual service frequency is reduced (or increased) depending on the hours of daily operation of the bus service (see Exhibit 16), the difficulty of crossing the street on foot (see Exhibit 17), and the difficulty of walking the length of the street segment (see Exhibit 18).

Exhibit 15. FDOT Bus LOS Thresholds.

LOS	Adjusted Service Frequency (vehicles per hour)
A	> 6.0
B	4.01 to 6.0
C	3.0 to 4.0
D	2.0 to 2.99
E	1.0 to 1.99
F	< 1.0

Exhibit 16. Bus Span of Service Adjustment Factors for Bus LOS (SpanAdj).

Daily Hours of Service	SpanAdj
19 – 24	1.15
17 – 18	1.05
14 – 16	1.00
12 – 13	0.90
4 – 11	0.75
0 – 3	0.55

$$ASF = SF * PLOSAdj * CrossAdj * SpanAdj \qquad \text{(Eq. 2)}$$

Where

ASF = Adjusted Service Frequency (vph)
SF = Actual Service Frequency (vph)
PLOSAdj = Adjustment factor for pedestrian LOS
CrossAdj = Adjustment factor for street crossing difficulty for pedestrians
SpanAdj = Adjustment factor for daily hours of bus service.

The FDOT Q/LOS Handbook uses the HCM LOS criteria and thresholds for urban streets for the automobile level of service.

The Handbook provides two LOS estimation procedures for planning level analyses: Generalized Planning Analysis, and Conceptual Planning Analysis. Generalized planning analysis is a "broad type of planning application such as statewide analyses, initial problem identification, and future year analyses." Conceptual planning is a "preliminary engineering application detailed enough to reach a decision on design concept and scope."

Generalized planning analysis consists of look-up tables of maximum service volumes for auto LOS by facility type, area type, number of lanes, and median type. The bicycle and pedestrian LOS look-up tables provide maximum auto service volumes according to the percentage of sidewalk and bicycle lane coverage on the road segment.

Exhibit 17. Roadway Crossing Adjustment Factors for Bus LOS (CrossAdj).

Conditions that must be met				
Arterial Class	Median	Mid-Block Through Lanes	Auto LOS	CrossAdj
I	All situations	2	A or B	1.05
II	All situations	2	A, B, or C	1.05
III	All situations	≤ 4	A or B	1.05
IV	All situations	≤ 4	All LOS	1.05
I	None or non-restrictive	≥ 4	B-F	0.80
I	Restrictive	≥ 8	All LOS	0.80
II	None or non-restrictive	≥ 4	C-F	0.80
II	Restrictive	≥ 8	All LOS	0.80
III	None or non-restrictive	≥ 4	D-F	0.80
III	Restrictive	≥ 8	All LOS	0.80
All cases not included above =				1.00

Exhibit 18. Pedestrian LOS Adjustment Factors for Bus LOS (PLOSAdj).

Pedestrian LOS	Adjustment Factor
A	1.15
B	1.10
C	1.05
D	1.00
E	0.80
F	0.55

Exhibit 19. FDOT Bicycle and Pedestrian LOS Score Thresholds.

LOS	Score
A	< 1.5
B	> 1.5 and < 2.5
C	> 2.5 and < 3.5
D	> 3.5 and < 4.5
E	> 4.5 and < 5.5
F	> 5.5

Conceptual planning analysis evaluates urban street facility level of service on a segment by segment basis. The segment levels of service for auto and bus are averaged (weighted by length) to obtain a facility LOS for each mode. For pedestrians and bicycles, the facility LOS is the average of the segment LOS for the single worst segment of the facility and the length weighted average segment LOSs for all of the other segments of the facility. The level of service at points (intersections) within the facility is not taken into account in the estimation of facility LOS.

Bicycle LOS

Florida's quality of service perspective is based on the bicyclists' perspective of the safety of sharing the roadway environment with motor vehicle traffic. This is based on the Bicycle LOS Model, originally developed by Sprinkle Consulting Inc. (SCI), and which has been applied to more than 200,000 miles of roadways in the United States (including throughout Florida) and Canada. In the Bicycle LOS Model, bicycle levels of service are based on five variables with relative importance ordered (according to relative absolute value of "t" statistics) in the following list:

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

Average effective width is largely determined by the width of the outside travel lane and [any attendant bicycle lane] striping, but also includes other factors such as the effects of on-street parking and drainage grates. Each of the variables is weighted by coefficients derived by stepwise regression modeling. A numerical LOS score, generally ranging from 0.5 to 6.5, is determined and stratified to a LOS letter grade. Thus, unlike the determination of automobile LOS in the HCM2000, in which there is usually only one service measure (e.g., average travel speed), bicycle LOS is determined based on multiple factors.

The facility segment bicycle LOS score (BLOS) is estimated according to the following equation and the equivalent letter grade LOS is reported according to Exhibit 19.

$$BLOS = 0.507 \ln (Vol_{15}/L) + 0.199SP_t(1 + 10.38HV)^2 + 7.066(1/PR_5)^2 - 0.005(W_e)^2 + 0.760 \quad \text{(Eq. 3)}$$

Where

BLOS = Bicycle level of service score

ln = Natural log

Vol_{15} = Directional motorized vehicle count in the peak 15 minute time period

L = Total number of directional through lanes

SP_t = Effective speed factor = $1.1199 \ Ln(SP_p - 20) + 0.8103$

SP_p = Posted speed limit (a surrogate for average running speed)

HV = Percentage of heavy vehicles

PR_5 = FHWA's five point pavement surface condition rating

W_e = Average effective width of outside through lane

Many of the factors in the Bicycle LOS Model equation are also used to determine automobile LOS in the HCM2000 methodology and are either logarithmic or exponential functions. Logarithmic and exponential functions make the importance of the variables differ significantly depending on the precise value. For example, the bicycle LOS drops dramatically as motorized vehicle volumes initially rise, but then tends to deteriorate more slowly at higher volumes. Another example is the effect of motorized vehicle speed. At low speeds, the variable is not as significant in determining bicycle LOS, but at higher speeds it plays an ever-increasing role.

Pedestrian LOS

The pedestrian LOS model was developed for FDOT in a manner similar to that for the bicycle model. The pedestrian LOS model reflects the perspective of pedestrians sharing the roadside environment with motor vehicles and has been applied to cities in Florida and elsewhere in the United States. Pedestrian levels of service are based on four variables in the following list:

- Existence of a sidewalk,
- Lateral separation of pedestrians from motorized vehicles,

- Motorized vehicle volumes, and
- Motorized vehicle speeds.

Each of the variables is weighted according to stepwise regression modeling: A numerical LOS score, generally ranging from 0.5 to 6.5, is determined along with the corresponding LOS letter grade. Thus, like the bicycle LOS approach (but unlike the automobile approach), pedestrian LOS is determined based on multiple factors.

In developing the pedestrian LOS Model, the researchers, SCI staff under contract with FDOT, conducted stepwise regression analyses using 1,315 real-time observations from a research effort conducted in 2000 in Pensacola, Florida.

Many of the terms in the pedestrian LOS model equation are also used to determine automobile LOS in the HCM methodology and bicycle LOS in the bicycle LOS model. The logarithmic and exponential functions make the importance of the variables differ significantly depending on the precise value.

The pedestrian LOS score (PLOS) is estimated according to the equation below. (This formula differs from the formula originally produced as part of the Pensacola survey. FDOT has retained the variables from the original survey but the coefficients and constant have been changed. See Phillips, Karachepone, and Landis [**9**] for original PLOS equation.) The PLOS score is entered in the above table to obtain the equivalent LOS letter grade.

$$PLOS = -1.2276 \ln (W_{ol} + W_l + f_p \times \%OSP + f_b \times W_b + f_{sw} \times W_s) + 0.0091\,(Vol_{15}/L) + 0.0004\,SPD^2 + 6.0468 \qquad \text{(Eq. 4)}$$

Where

PLOS = Pedestrian level of service score

Ln = Natural log

W_{ol} = Width of outside lane

W_l = Width of shoulder or bicycle lane

f_p = On-street parking effect coefficient (=0.20)

%OSP = Percent of segment with on-street parking

f_b = Buffer area barrier coefficient (=5.37 for trees spaced 20 feet on center)

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

f_{sw} = Sidewalk presence coefficient (= 6 − 0.3Ws)

W_s = Width of sidewalk

Vol_{15} = Count of motorized vehicles in the peak 15 minute period

L = Total number of directional through lanes

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

2.2 Evaluation Against NCHRP 3-70 Framework Objectives

This section evaluates the three major guidebooks on level of service against the NCHRP 3-70 objectives for a multimodal level of service framework for urban streets. Exhibit 20 summarizes the conclusions. The following paragraphs explain these conclusions in more detail.

Highway Capacity Manual

Exhibit 21 critiques the LOS criteria used in the *Highway Capacity Manual*. Exhibit 22 critiques the intermodal relationships incorporated in the *Highway Capacity Manual*.

Exhibit 20. Evaluation of Major LOS Manuals Against NCHRP 3-70 Framework Objectives.

Framework Objective	HCM	TCQSM	FDOT Q/LOS
1. National Application	Designed for Nation	Designed for Nation	Designed for State
2. LOS is Travelers' Perspective	Claimed, but no proof	A blend of traveler and operator perspectives	A blend of HCM, TCQS and traveler surveys
3. Applicable to Urban Streets	Yes	Yes	Yes
4. Considers All factors within ROW	Many factors considered, but not all	Many factors considered, but not all	Many factors considered, but not all
5. Safety and Economic Factors	No	No	Perceived safety included
6. Comparable Modal LOS	Uses speed for auto, bike, and pedestrian, but not transit	Only considers transit	Different LOS measures by mode
7. Modal Interactions	Some but not all–See table below.	Some but not all–See table below.	Some but not all–See table below.
8. LOS Reflects All Movements	Only Through	Yes, all bus service on arterial is counted	Only Through
9. No Averaging Across Modes	Does not average	Considers only single mode	Does not average
10. Not Limited by HCM Limits	Limited by HCM	HCM limits not applicable	Limited by HCM

ROW = Right of Way
HCM = Highway Capacity Manual
LOS = Level of Service

Exhibit 21. HCM LOS Criteria for Urban Street.

Mode	LOS Criterion	Comments
Auto	Mean auto speed for through traffic	Applies only to arterials, not collector or local streets
Transit	Hours of Daily Service, Reliability	These are the two segment LOS criteria for availability and comfort/convenience
Bicycle	Mean speed of bicycle through traffic	Applies only if designated bicycle lanes are present
Pedestrian	Mean speed of pedestrian through traffic	Applies only if sidewalk is present

National Multimodal Application: The HCM is designed to be applied nationally for all four modes (i.e., auto, transit, bicycle, and pedestrian).

Level of Service from a Traveler's Perspective: The HCM claims to predict LOS from the traveler's perspective, but there is little evidence to support this claim. The service measures were developed in committee without specific research of traveler opinions to support the selected service measures.

Applicable to Urban Streets: The HCM is designed to be applied to urban arterials where the through movement is the only function of the street. It may be less applicable to collectors where both through movement and access are important functions of the street.

Considers All Factors Within Right of Way: The auto LOS methodology incorporates all geometric and signal operation factors considered relevant to the prediction of auto speed. The transit LOS method does not yet have a methodology for incorporating the effects of signal operation, traffic flow, and other factors in the right of way that can influence bus service reliability. The pedestrian and bicycle LOS

Exhibit 22. The Modal Operational Inter-Relationships in the HCM.

Mode	Auto	Transit	Bicycle	Pedestrian
Auto	Higher auto volumes reduce auto LOS.	The effect cannot be computed. Higher auto volumes may reduce reliability, but no estimation method is available in the HCM. Higher auto volumes have no direct effect on span of transit service.	Higher auto volumes indirectly affect bicycle LOS by affecting delays at signals.	For signalized intersections, higher auto volumes indirectly affect pedestrian LOS by affecting delays at signals. For unsignalized intersections, higher auto volumes directly affect pedestrian delays and, therefore, pedestrian LOS.
Transit	Higher transit volumes reduce capacity and increase delays at signalized intersections	The effect cannot be computed. Higher bus volumes may reduce reliability, but no effect on span of service.	Higher transit volumes reduce capacity and increase delays at signalized intersections	Higher transit volumes reduce capacity and increase delays at signalized intersections
Bicycle	Higher bicycle volumes reduce capacity and increase delays at signalized intersections	The effect cannot be computed. Heavy bicycle volumes may reduce reliability, but no impact on span of service.	Higher bicycle volumes reduce mean segment speed which reduces LOS (HCM Exhibit 19-3)	Higher bicycle volumes have **NO** effect on walk speed or delay at signals.
Pedestrian	Higher pedestrian volumes reduce capacity and increase delays at signalized intersections	The effect cannot be computed. Higher pedestrian flows may affect reliability but not span of service.	Pedestrian flows between 1 and 60/hr. may indirectly affect bicycle LOS by affecting delays at signals. Higher volumes have **NO** effect.	The effect is indirect except at unsignalized crossings where higher pedestrian flows affect the group critical gap and therefore pedestrian delay.

Shaded boxes indicate weak or non-existent inter-relationships. No effect means that a change in modal volume has no effect on LOS as computed per the HCM.

methodologies incorporate the effects of intersections on average pedestrian and bicycle speeds, but do not consider other potential factors (such as interference).

Safety and Economic Factors: Safety and economic factors are not included in any of the LOS methodologies.

Comparable Modal LOS: The HCM uses the same service measure, speed, to predict traveler LOS on urban streets for auto, bicycle, and pedestrians. Transit does not use speed for LOS at the urban street level. However the LOS thresholds for each mode were selected by committee and are not backed up by research indicating comparability of LOS values across modes.

Modal Interactions: The HCM incorporates many but not all of the potential cross-modal influences on level of service. Exhibit 21 highlights the key LOS criteria for each mode. Exhibit 22 then shows how the various modes can affect each of these key LOS criteria.

The HCM takes into account the effects of pedestrians, bicycles, and transit on auto delay at signalized intersections. The signalized intersection delay in turn affects the estimated mean speed of through traffic on the urban street. The mean speed is the LOS criterion for an urban street in the HCM.

Higher auto volumes indirectly affect bicycle and pedestrian LOS in the HCM method by affecting the signal timing at the intersections. Longer cycle lengths and longer red times would increase bicycle and pedestrian delay and reduce their level of service on the street.

Higher auto volumes would indirectly affect transit reliability by increasing the probability of congestion, but the HCM provides no method for estimating this effect. Thus the effect of auto volumes on transit LOS cannot currently be accounted for using the available HCM procedures.

The effects of pedestrians on bicycle level of service and the effects of bicycles on pedestrian level of service are accounted for in the analysis of off-street facilities, but not for on-street facilities in the HCM.

Higher transit volumes, by reducing capacity and increasing congestion, can adversely affect bicycle and pedestrian LOS in the HCM method by affecting the cycle length and red times at signalized intersections.

LOS Reflects All Movements: The HCM focuses on predicting urban street LOS only for the through movement for auto, bicycle, and pedestrian. The transit LOS includes any service on the street and at each stop.

Averaging LOS Across Modes: The HCM does not average LOS across modes.

HCM Limitations: The HCM lists nine conditions (p. 15-1) that are not accounted for in the current urban streets methodology for auto LOS:

1. Presence or lack of on-street parking;
2. Driveway density or access control;
3. Lane additions leading up to or lane drops leading away from intersections;
4. The effects of grades between intersections;
5. Any capacity constraints between intersections (such as a narrow bridge);
6. Mid-block medians and two-way left-turn lanes;
7. Turning movements that exceed 20 percent of the total volume on the street;
8. Queues at one intersection backing up to and interfering with the operation of an upstream intersection; and
9. Cross-street congestion blocking through traffic.

Transit TCQSM Critique

Exhibit 23 critiques the intermodal relationships in the *Transit Capacity and Quality of Service Manual*.

National Multimodal Application: The TCQSM is designed to be applied nationally for transit only.

Level of Service from a Traveler's Perspective: The TCQSM LOS measures are based on surveys that identified service factors important to traveler perceptions. The LOS E/F thresholds were set based on a project team/project panel consensus of undesirable service from a passenger standpoint; the other thresholds ideally represent points where a noticeable change in service quality occurs (e.g., when no more seats are left), and otherwise represent even ranges of the service measure between LOS A and LOS F.

Applicable to Urban Streets: The TCQSM is oriented to the transit service features, not the street facility. LOS measures are provided for stops, routes, and the system as a whole. The measures must be adapted for use on a specific street facility.

Considers All Factors Within Right of Way: The TCQSM does not currently provide a methodology for taking into account the effects of street facility characteristics on transit LOS. Walk and drive accessibility are currently not included in bus stop level of service. No methodology is currently available for estimating the effect of traffic congestion and signal operation on transit service reliability.

Safety and Economic Factors: Safety and economic factors are not included in the LOS methodology.

Comparable Modal LOS: The TCQSM focuses on transit. The selected service measures are specific to transit and are not comparable with those for other modes.

Modal Interactions: The TCQSM incorporates many but not all of the potential cross-modal influences on level of service. Exhibit 23 shows how the various modes can affect the key LOS criteria for transit.

LOS Reflects All Movements: The transit LOS includes any service on the street and at each stop.

Averaging LOS Across Modes: The TCQSM does not average LOS across modes.

Exhibit 23. The Modal Operational Inter-Relationships in the TCQSM, Second Edition.

Mode	Auto	Transit	Bicycle	Pedestrian
Auto	Not Applicable	Higher auto volumes may reduce reliability, but no estimation method is available in the TCQSM. Reduced reliability affects passenger loads. Auto volumes, street width, and signal timing affect street crossing difficulty which can reduce service coverage. Higher auto volumes reduce bus speed, which affects transit-auto travel time, but no estimation method is available in the HCM or TCQSM.	Not Applicable	Not Applicable
Transit	Not Applicable	Higher bus volumes reduce bus speed, which affects transit-auto travel time. High bus volumes relative to bus capacity affect reliability, but no estimation method is available in the TCQSM.	Not Applicable	Not Applicable
Bicycle	Not Applicable	No estimation method is available in the HCM or TCQSM for the effect of bikes on bus speed or reliability.	Not Applicable	Not Applicable
Pedestrian	Not Applicable	Pedestrian crossing volumes affect right-turn capacity, which affects bus lane capacity, which affects bus travel time and reliability, but no estimation method is available in the TCQSM.	Not Applicable	Not Applicable

Shaded boxes indicate weak or non-existent inter-relationships. No effect means that a change in modal volume has no effect on LOS as computed per the TCQSM.

HCM Limitations: The HCM limitations are irrelevant to the TCQSM.

Florida DOT Q/LOS Handbook

Exhibit 24 critiques the LOS criteria in the Florida DOT Q/LOS Handbook. Exhibit 25 critiques the intermodal relationships in the Florida DOT Q/LOS Handbook.

National Multimodal Application: The FDOT Q/LOS Handbook is designed to be applied statewide for all four modes (i.e., auto, transit, bicycle, and pedestrian).

Level of Service from a Traveler's Perspective: The Q/LOS Handbook is a blend of local research on bicycle/pedestrian perceptions of LOS and the two national manuals—the HCM and TCQSM. The Q/LOS Handbook thus shares some of the weaknesses of the national manuals. The HCM claim that auto LOS accurately reflects traveler perception has not been verified. The TCQSM transit LOS is a blend of traveler perceptions and transit operator objectives. The pedestrian and bicycle LOS measures have been experimentally verified against traveler perceptions.

Applicable to Urban Streets: The FDOT Q/LOS Handbook is designed to be applied to urban arterials where the through movement is the only function of the street. It may be less applicable to collectors where both through movement and access are important functions of the street.

Considers All Factors Within Right-of-Way: Like the HCM, the FDOT Q/LOS Handbook auto LOS methodology incorporates all geometric and signal operation factors considered relevant to the prediction of auto speed. The transit LOS method does not yet have a methodology for incorporating the effects of signal operation, traffic flow, and other factors in the right-of-way that can influence bus service reliability. The pedestrian and bicycle LOS methodologies incorporate all factors related to the right-of-way that were found to significantly affect perceived LOS.

Safety and Economic Factors: Economic factors are not included in any of the LOS methodologies. Perceived safety is an underlying factor in the pedestrian and bicycle LOS methods.

Comparable Modal LOS: The FDOT Q/LOS Handbook measures for pedestrian and bicycle modes are probably comparable in terms of their measurement of degree of satisfaction, but no actual tests of this conjecture have been performed. The auto and transit LOS measures are generally not comparable with the pedestrian and bicycle LOS measures.

Exhibit 24. FDOT LOS Criteria for Urban Street.

Mode	LOS Criterion	Comments
Auto	Mean auto speed for through traffic	
Transit	Frequency of Service	Has modifiers for walk access and hours of service
Bicycle	Index	Based on design and traffic volumes
Pedestrian	Index	Based on design and traffic volumes

Exhibit 25. The Modal Operational Inter-Relationships in the FDOT Q/LOS Handbook.

Mode	Auto	Transit	Bicycle	Pedestrian
Auto	Higher auto volumes reduce auto LOS	Higher auto flows have **NO** effect on transit frequency, span of service, or walk access	Higher auto volumes and/or higher speeds reduce bicycle LOS	Higher auto volumes and/or higher speeds reduce pedestrian LOS
Transit	Higher transit volumes reduce capacity and increase delays at signalized intersections	Higher bus volumes mean higher frequencies, which increases transit LOS	Higher heavy vehicle volumes reduce bicycle LOS	Higher heavy vehicle volumes reduce pedestrian LOS
Bicycle	Higher bicycle volumes reduce capacity and increase delays at signalized intersections	Higher bike flows have **NO** effect on transit frequency, span of service, or walk access barriers	Higher bicycle volumes have **NO** effect on BLOS. Better design affects BLOS.	Higher bicycle volumes have **NO** effect on PLOS. Better bike design may affect PLOS.
Pedestrian	Higher pedestrian volumes reduce capacity and increase delays at intersections	Higher pedestrian volumes have **NO** effect on transit LOS. Better pedestrian facilities improve transit LOS.	Higher pedestrian volumes have **NO** effect on BLOS. Better pedestrian design may affect PLOS.	Higher pedestrian volumes have **NO** effect on PLOS. Better design affects PLOS.

Shaded boxes indicate weak or non-existent inter-relationships. No effect means that a change in modal volume has no effect on LOS as computed per FDOT.

Modal Interactions: The FDOT Q/LOS Handbook incorporates many but not all of the potential cross-modal influences on level of service. Exhibit 24 highlights the key LOS criteria for each mode. Exhibit 25 shows how the various modes can affect each of these key LOS criteria.

2.3 Conclusions

Current Agency Practices

Public agencies make extensive use of the *Highway Capacity Manual* and the Florida *Quality/Level of Service Handbook* for planning and designing urban streets. The *Transit Capacity and Quality of Service Manual* is a recent development and has not yet seen extensive adoption by public agencies.

Level of service is used on a daily basis in most public agencies to assess the adequacy of the design of urban streets, to assess the effects of new development on urban street operations, and to identify the appropriate mitigation measures for new development. These analyses however focus primarily on auto level of service.

The survey of current agency practices found little actual use of level of service for the planning or design of urban streets for transit, bicycle, and pedestrian modes, except in the State of Florida where it is a recent development. There is, however, a great deal of interest among public agencies in acquiring the ability to estimate and forecast level of service for all four modes, especially if the issue of comparability of results across modes can be achieved.

The Major Level of Service Manuals

The existing LOS frameworks outlined in the major LOS manuals generally do not provide comparable LOS results across modes. This is due to different definitions of level of service and different measurement scales used by the various manuals for each mode:

1. The HCM Urban Street LOS measures are not based on surveys of traveler satisfaction and thus cannot be compared with the traveler satisfaction based LOS measures contained in the TCQSM and FDOT manuals.
2. The TCQSM provides no single LOS result for transit but several different dimensions of LOS making mode-to-mode comparisons difficult. The TCQSM LOS measures are derived from surveys of traveler satisfaction.
3. The FDOT multimodal framework, because it relies on the HCM and TCQSM manuals for auto and transit, suffers from the same comparability limitations as those manuals. The auto LOS in particular is not comparable with the bike and pedestrian LOS scales, because they are based on different dimensions of perceived and measured traveler satisfaction.

The major existing LOS manuals are spotty in their incorporation of known modal interactions on modal LOS. Either the selected modal LOS measure (such as hours of bus service) is insensitive to the effects of other modes or an accepted methodology has not yet been established for predicting the intermodal effects.

The Florida bicycle and pedestrian level of service models have a strong scientific basis, but their incorporation in the national manuals has been hindered by the perception (valid or not) that they are based strictly on data from a single city in a single state, even though they have been applied in many jurisdictions around the United States. There are also concerns at the national level (valid or not) that the level of service measured in Florida for bicycles and pedestrians is a different dimension of traveler satisfaction not related to traditional traffic operations analysis and, therefore, incompatible with the national manuals.

Implications for Research Project

The major issues for establishing a multimodal level of service framework are as follows:

1. Establishing comparability of meanings for LOS grades across modes,
2. Establishing models for predicting LOS that reflect the interactions among modes in an urban street setting, and
3. Establishing a credible national basis for the multimodal LOS framework and models.

CHAPTER 3

Literature Review

This chapter reviews the recent published research into multimodal level of service. The literature review is grouped by research into traveler perceptions of level of service for auto, transit, bicycle, and pedestrian, and research into multimodal level of service frameworks.

3.1 Auto Driver Perceptions of LOS

Researchers have focused on auto driver perceptions of quality of service for urban streets, signalized intersections, and rural roads. Researchers have used field surveys (where subjects are sent into the field to drive a fixed course) and video laboratories and have laboratory interviews to identify key factors affecting perceived LOS and to obtain LOS ratings for different field conditions.

Level of service has been defined by researchers in various ways. For example, LOS A may be defined as "excellent," "best," or "very satisfied" depending on the researcher. Others have defined LOS in terms of hazards and conflicts (e.g., number of vehicle-to-vehicle and vehicle-to-pedestrian conflicts).

Some have developed models that predict the average LOS rating, while others have developed models that predict the percentage of responses for each LOS grade.

Several researchers have noted that drivers do not perceive six levels of service. Some researchers have proposed as few as three levels of service, while one researcher suggested a shift of the entire LOS spectrum by one level of service so as to combine LOS A and B and subdivide LOS F.

Some of the latest research incorporates "fuzzy logic" in the translation of user perceptions into letter grade levels of service.

Urban Street LOS

While the HCM's focus on measuring delay, percent of time spent following, and average travel speed (to name a few) offers a conceptual link to how the user perceives the transportation system's level of service, a review of the existing literature by Flannery et al. (2005) [**10**] found little research that empirically investigates these links. Flannery et al. conclude that a comprehensive research approach is needed to identify and prioritize the factors important to drivers followed by research that models and calibrates these factors.

In a study comparing users' perceptions of urban street service quality, Flannery et al. (2004) [**11**] found that HCM 2000 methods only predicted 35 percent of the variance in mean driver ratings, suggesting LOS does not completely represent driver assessments of facility performance.

Colman [**12**] sent 50 students to drive various arterial streets and compare the HCM level of service (based on speed) against their own perception of quality of service. The student's perceived speed thresholds for urban street level of service tended to be 4% to 24% higher than the HCM speed thresholds. They expected better service for a given letter grade than the HCM.

Seeking to identify the key factors that influence user perceptions of urban street LOS, Pecheux et al. (2004) [**13**] used an in-vehicle survey and interview approach to determine the factors that affect drivers' perceptions of quality of service. They identified 40 factors that are relevant to these perceptions, including roadway design, urban street operations, intersection operations, signs and markings, maintenance, aesthetics, and the behaviors of other road users. A study by Flannery et al. (2005) provides support for this collection of important factors. Flannery et al. had drivers rate video segments of travel on urban streets and then select and rank from a list of 36 factors the 3 factors that they considered to be most important to LOS. Mean driver ratings had statistically significant correlations with operational and design characteristics, and aesthetics, including the following variables: travel time, average travel speed, number of stops, delay, number of signals, lane width, the presence of trees, and quality of landscaping.

An FHWA-sponsored study of customer satisfaction (SAIC [**14**]) sought to determine what factors influence perceived driver satisfaction on urban streets. Drivers drove with two researchers in their vehicle and talked aloud about the factors that made them feel satisfied or dissatisfied with the drive they were experiencing in real time. The study was conducted in four locations and one pilot study location. The locations consisted of two small urban areas (Tallahassee, Florida, and Sacramento, California) and two large urban areas (Chicago, Illinois, and Atlanta, Georgia). In each location, routes requiring approximately 30 to 40 minutes of drive time were selected. Each of the routes incorporated characteristics included in Exhibit 26, taken from the HCM 2000. In small urban areas, the focus was on suburban and intermediate characteristics; in large urban areas, the focus was on intermediate and urban characteristics. Twenty-two participants were in the four study locations; their characteristics are described in Exhibit 27.

The findings from this study resulted in 42 Quality of Service (QOS) factors for urban streets that can be categorized into several investment areas. Exhibit 28 contains the identified factors according to driver transcripts and completed surveys.

The researchers further refined the identified QOS factors into nine proposed measures of effectiveness (MOEs) shown in Exhibit 29. The proposed MOEs reflect the input provided by the participants in the study, but combine like QOS factors into, for the most part, measurable performance measures. For example, participants in the study often commented negatively when they were forced to slow down or stop because of poor arterial design that did not provide for bus pullouts, turning facilities, on-street parking maneuvers, and poor access management that created many merge/diverge situations. The authors of this study have concluded that the MOE number of stops best represents the views of the participants in this study.

Intersection LOS Research

Sutaria and Haynes [**15**] focused on determining the different levels of service at signalized intersections. The researchers investigated 30 signalized, isolated, fixed-time intersections in the Dallas-Fort Worth area and determined that only 1 intersection experienced the full range of LOS categories (then based on Load Factor defined as the ratio of the total number of green signal intervals fully utilized by traffic during the peak hour to the total number of green intervals). The intersection of Lemmon and Oaklawn Avenues in Dallas

Exhibit 26. Route Characteristics.

Criterion	Route (Design) Category Suburban	Intermediate	Urban
Driveway/access density	Low density	Moderate density	High density
Arterial type	Multilane divided; undivided or two-lane with shoulders	Multilane divided or undivided; one-way two-lane	Undivided one-way, two-way, two or more lanes
Parking	No	Some	Significant
Separate left-turn lanes	Yes	Usually	Some
Signals/mile	1-5	4-10	6-12
Speed limit	40-45 mph	30-40 mph	25-35 mph
Pedestrian activity	Little	Some	Usually
Roadside development	Low to medium density	Medium to moderate density	High density

Exhibit 27. Participant Characteristics.

Field Site	Number of Participants	Ages	Sex
Northern Virginia (Pilot location)	4	2 20 - 30 year olds 2 35 - 50 year olds	2 women 2 men
Chicago	5	2 20 - 30 year olds 3 35 - 50 year olds 0 60 - 75 year olds	3 women 2 men
Tallahassee	5	1 20 - 30 year old 2 35 - 50 year olds 2 60 - 75 year olds	3 women 2 men
Atlanta	6	0 20 - 30 year olds 3 35 - 50 year olds 3 60 - 75 year olds	3 women 3 men
Sacramento	6	1 20 - 30 year old 3 35 - 50 year olds 2 60 - 75 year olds	4 women 2 men

Exhibit 28. Driver-Identified QOS Factors For Urban Streets.

Investment Area	QOS Factor	
Cross-Section Roadway Design	Lane width Pedestrian/bicyclist facilities # of lanes/roadway width Bus pull-outs Turning lanes/bays	Parking Lane drop/add Access management Medians Two-way center left turn lane
Arterial Operations	Number of traffic signals Presence of large vehicles Volume/congestion	Travel time Traffic flow Speed
Intersection Operations	Signal failure/inefficient signal timing Turning	Timing of signals Traffic progression
Signs and Markings	Quality of pavement markings Advance signing Lane guidance—signs Too many signs	Lane guidance—pavement markings Sign legibility/visibility Sign presence/usefulness
Maintenance	Pavement quality	Overgrown foliage
Aesthetics	Presence of trees Medians with trees Visual clutter	Cleanliness Roadside development
Other Road Users	Illegal maneuvers Careless/inattentive driving Driver courtesy Use of turn signals	Aggressive drivers Pedestrian behavior Improper/careless lane use Blocking intersection
Other	Intelligent transportation systems	Roadway lighting Planning

Exhibit 29. Proposed MOEs For Urban Streets.

MOEs	QOS Factors
Number of stops	Turning lanes/bays Bus pull-out areas On-street parking Two-way center left-turn lane Access management Lane drop/add
Urban street capacity	Heavy vehicles Lane width Number of lanes/roadway width
Intersection efficiency	Signal timing (cycle length/cycle split) Provision for turning vehicles
Urban street efficiency	Progression Number of traffic signals Travel time Travel speed
Traffic volume	Volume/congestion Traffic flow Speed Travel time
Positive guidance	Quality of pavement markings Sign legibility/visibility Sign presence/usefulness Lane guidance—signs Lane guidance—pavement markings Advance signing Too many signs (clutter/distracting) Visual clutter
Pavement quality	Pavement quality
Perceived safety	Presence of medians Lane width Pedestrian/bicycle facilities Access management
Area type	Roadside development Cleanliness Trees Visual clutter

was filmed using 16mm cameras for several hours to gather several film clips ranging from A to E Level of Service. For the study, 14 film clips, ranging from 42-193 seconds, were shown to the participants. The film clips were broken into two groups: microviews that showed the traffic situation from the view of an individual driver seated in an automobile and macroviews that showed the overall traffic situation on a given approach from high above. Seven clips, ranging from LOS A to LOS E, in each group were shown to participants.

There were 310 participants in the study. The participants were given a questionnaire about their perceptions of signalized intersections before viewing the films collected in the field. The participants were asked to indicate, in order of importance, the factors that affect their perceived views of quality of flow at signalized intersections. They were given five factors to rank: delay, number of stops, traffic congestion, number of trucks/buses, and difficulty in lane changing. It does not appear that definitions of the factors were provided to the participants.

Before viewing the films, the participants ranked the factors as follows:

1. Delay,
2. Number of stops,
3. Traffic congestion,
4. Difficulty in lane changing, and
5. Number of trucks/buses.

After viewing the films, the rankings changed slightly as follows:

1. Delay,
2. Traffic congestion,
3. Number of stops,
4. Difficulty in changing lanes, and
5. Number of trucks/buses.

After viewing each of the 14 film clips, the participants were also asked to score the service quality of the various film segments on two different opinion scales: a 6-point scale (Scale A) and one of five descriptions (Scale B) (See Exhibits 30 and 31.)

Based on input gathered from this study, the researchers developed a nomograph that depicted the relationship between Average Intersection Delay (AID), Load Factor (LF), and volume-to-capacity ratio (v/c) to perceived or rated level of service. The researchers went on to make three recommendations:

- AID should be used to predict level of service.
- Similar studies should be conducted on signalized intersections without full actuation.
- Simultaneous filming and field studies should be conducted to allow for accurate measurement of traffic engineering measures captured on film.

Based on the findings of this single research study, the Highway Capacity and Quality of Service Committee overhauled the 1985 HCM to represent level of service at signalized intersections by AID versus LF.

The authors state, "Field studies and the attitude survey provided data for the development of two psychophysical models. Statistical analysis indicated that average individual delay correlated better with level of service rating than with measured load factor and encompassed all levels of service. Of all parameters affecting levels of service, load factor was rated highest by road users."

Ha, Ha, and Berg [**16**] developed models for predicting the number of conflict opportunities (potential conflicts) at an intersection as a function of signal timing, intersection geometry, and turn volumes. Based on a review of previous investigations, they limited their analysis to left-turn and rear-end accident analyses. The "total hazard" at an intersection is the sum of the likely number of rear-end and left-turn accidents multiplied by their severity. The total hazard is converted to a hazard index by dividing by the number of vehicles. The

Exhibit 30. Sutaria and Haynes Scale A —Point Rating.

Rating	Description
5	= Excellent
4	= Very Good
3	= Good
2	= Fair
1	= Poor
0	= Very Poor

Exhibit 31. Sutaria and Haynes Scale B – Descriptive Rating.

Description Rating of Quality of Service
I would describe the traffic situation presented in this film segment as a condition of:
• Free flow or as "free flowing" as can be expected if there is a traffic signal at the intersection under study. OR
• Tolerable delay, and nearly as good as could be expected at a signalized intersection. OR
• Considerable delay but typical of a lot of ordinary signalized intersections during busy times. OR
• Unacceptable delay and typical of only the busiest signalized intersections during the rush hour. OR
• Intolerable delay and typical only of the worst few signalized intersections I have seen.

letter-grade level of service is then determined from a hazard index look-up table.

Zhang and Prevedouros [**17**] developed a model of vehicle-to-vehicle and vehicle-to-pedestrian conflicts and blended it with the existing HCM delay LOS criteria for signalized intersections to obtain an LOS model that combines safety risk with traditional delay measures of LOS. Two delay and safety indices are computed—one for pedestrians, the other for vehicles. Each index is computed as a weighted sum of potential conflicts and delay. The weights are analyst specified. The two indices are then weighted by pedestrian and vehicle volumes, respectively, to obtain a weighted average delay and safety index for the intersection. No surveys of traveler perception were performed. This paper was oriented toward methodological approaches rather than traveler perception.

Several recent studies of intersection LOS have also cast some doubt on the HCM's methods. Zhang and Prevedouros (2004) [**18**] investigated motorists' perceptions of LOS at case study signalized intersections and found that, although the HCM 2000 predicts that permitted left-turn phases provide a higher level of service, users ranked protected left-turn phased intersections higher. This finding suggests that users may be including the perceived safety benefits of protected phasing at these case study locations in their assessments of LOS, in addition to delay. In a follow-up study, Zhang and Prevedouros (2005) [**19**] surveyed users' perceptions of service quality at intersections and found that users consider multiple factors beyond delay (as calculated by the HCM 2000), including signal efficiency, left-turn treatment, and pavement conditions. Delay scored relatively low among important factors. Drivers prefer to make left turns under protected left-turn signals, especially at large intersections. Safety was stated to be 3 to 6 times more important than delay, depending on the type of conflict.

The importance of safety in determining the level of service offered by an intersection is reflected in a study by Li et al. (2004) [**20**]. Li et al. used a "gray system" theory-based method to rank and evaluate the operational and safety performance of signalized intersections in mixed traffic conditions. The degree of saturation, average stopped delay, queue length, conflict ratio, and separation ratio are all used as parameters. Results of application in the urban area of Changsha, China, show that the method can be used to conduct a comprehensive (safety and operations) performance under mixed traffic conditions.

Pecheux, Pietrucha, and Jovanis [**21**] addressed users' perception of level of service at signalized intersections. The research objectives were to examine delay distributions, assess the accuracy of delay estimates, determine if current levels of service are appropriate, and identify factors affecting perceptions. The research used a video laboratory to show 100 participants (in groups of 7 to 10) a tape of a series of signalized intersections. The intersections portrayed on the tape were chosen in cities outside the local area to eliminate familiarity by the subjects, but in a location nearby so that local conditions were represented. The results of the study showed that, on average, subjects' delay estimates were fairly accurate, but widely variable on an individual basis. The study also showed that subjects perceived three or four levels and were more tolerant of delays than suggested by the HCM. At least 15 factors emerged from the group discussions that subjects identified as influential in their LOS ratings. These included delay, traffic signal efficiency, arrows/lanes for turning vehicles, clear/legible signs and road markings, geometric design of intersection, leading left-turn phasing scheme, visual clutter/distractions, size of intersection, pavement quality, queue length, traffic mix, location, scenery/aesthetics, and presence of pedestrians.

Use of Fuzzy Logic for LOS Modeling

Recent research has begun to use "fuzzy logic" to identify delay thresholds for rating the level of service of signalized intersections.

Fang and Pecheux [**22**] conducted a video laboratory of 98 subjects assessing the quality of service on 24 signalized intersection approaches. Cluster analysis (employing fuzzy thresholds) revealed that their subjects' quality of service assessments did not distinguish between the delays at HCM LOS A or B. The LOS ratings of their subjects, however, did distinguish two classes of delay for delays at HCM LOS F.

Zhang and Prevedouros [**23**] conducted a web-based stated preference survey of 1,300 volunteers. Their survey identified delay, pavement markings, presence of exclusive left-turn lanes, and protected left-turn phases, as factors significantly affecting the perceived level of service at a signalized intersection. Fuzzy inference was used to identify a distribution of LOS responses for a given physical condition. A percent confidence level was then reported for each LOS letter grade.

Lee, Kim, and Pietrucha [**24**] exposed 27 subjects to video clips of 12 signalized intersections. Subjects were asked to (1) rate their intersection experience as "poor," "acceptable," or "good" and (2) describe the relative importance of six criteria to their rating of the intersections. The six criteria evaluated were delay, gaps in cross street traffic while waiting, efficiency of traffic signal operation, visibility of signal, signing/markings, and physical features of the intersection.

Rural Road Research

Nakamura, Suzuki, and Ryu [**25**] conducted a field driving survey on a rural motorway section under uncongested traffic flow conditions and measured the driver's satisfaction with the road. The test area was a 9.3-km, 4-lane, rural basic motorway section between an on-ramp and an off-ramp. Twenty-four participants drove subject vehicles in both directions in the study segment for a total of 105 test runs. Videocameras were mounted on the test vehicle to record travel time, number of lane changes, time of a car-following situation by lane, and elapsed travel time by lane. The factor that most influenced driver satisfaction was traffic flow rate. The number of lane changes, the elapsed time of a car-following situation, and the driver's experience also affected the driver's evaluation of traffic conditions.

3.2 Transit Passenger Perceptions of LOS

Recent transit LOS research has focused on developing methods that incorporate more than just the characteristics of the available transit service, but measures of the environment in which that service operates. Fu et al. [**26**] developed a Transit Service Indicator (TSI) that recognizes that quality of service results from the interaction of supply and demand. The proposed index uses multiple performance measures (e.g., service frequency, hours of service, route coverage, and various travel-time components as well as spatial and temporal variations in travel demand). Tumlin et al. [**27**] developed a method that assesses transit performance in the context of different transportation environments. Quality of service criteria and scores reflect system performance in each area as well as provide for an aggregate measure of transit quality of service.

Other transit LOS research efforts have focused on developing or refining measures that can be easily calculated using existing transit agency data sources. Xin et al. [**28**] applied the recent edition of the TCQSM to evaluate the quality of transit service on several travel corridors in an urbanized area. Findings indicate that TCQSM measures (e.g., service frequency, hours of service, service coverage, and transit-auto travel time) are sensitive to planning/design variables (e.g., service headway, route structure, and service span) and, therefore, can be easily calculated by transit agencies using readily available data. Furth and Muller [**29**] noted that traditional transit service quality measures analyze waiting time and service reliability separately, underestimating the total costs of service unreliability which cause patrons to budget extra time waiting for transit to account for unreliability. Using AVL data, actual plus budgeted waiting time were measured and converted to costs. Findings indicate that service reliability improvements can reduce waiting cost as much as large reductions in service headways.

A Handbook for Measuring Customer Satisfaction

Morpace [**30**] presents a methodology for measuring customer satisfaction on an ongoing basis and the development of transit agency performance measures in response research findings.

The authors point out that the results of a customer satisfaction measurement program cannot be expected to drive agency decisions. Agency personnel must choose between improvements to address customer expectations and better education of customers about service parameters. They state the premise that, "Customers must always be first, [but] customers may not always be right".

They identify 10 Determinants of Service Quality, which are applicable to most service industries. The contention is that consumers use basically similar criteria in evaluating service quality. The 10 criteria are as follows:

1. Reliability (consistent and dependable);
2. Responsiveness (timeliness of service, helpfulness of employees);
3. Competence (able to perform service);
4. Accessibility;
5. Courtesy;
6. Communication;
7. Credibility;
8. Security;
9. Understanding the Customer; and
10. Tangibles.

They identify four transit market segments:

1. Secure customers very satisfied, definitely would repeat, definitely would recommend;
2. Favorable customers;
3. Vulnerable customers; and
4. At-risk customers.

They recommend that telephone benchmark surveys be used to establish baseline customer satisfaction with the transit service. These surveys are fairly expensive, so they also recommend a simpler survey approach, based on "impact scores," be used for tracking progress regularly.

The "impact score survey" is administered on-board and distributed to transit riders annually or biennially. The goal is to identify those attributes that have the greatest negative effect on overall customer satisfaction and also affect the greatest number of customers.

They suggest the use of an "Impact Score Technique" to identify the effect on customer satisfaction of "Things Gone Wrong" with the service. The score weights the effect of a service problem on customer satisfaction by the percentage of customers experiencing the service problem. The resulting score gives the expected change in the customer satisfaction index for the operator.

The steps to developing an impact score system are as follows:

1. Identify attributes with most impact on overall customer satisfaction. Compute gap scores.
2. Identify percent of customers who experienced the problem.
3. Create a composite index by multiplying gap score by incidence rate. Result is attribute impact score.

Example:

> Overall satisfaction rating for attribute 1 is
>
> 6.5 for those experiencing problem past 30 days
> 8.5 for those with no problem past 30 days
>
> The Gap score is 2.0 (8.5 – 6.5). If 50% of customers report having the problem, then the composite impact score is 2.0 * 50% or 1.00.

A Guidebook for Developing Transit Performance Measurement System

Although focused on implementing and applying a transit performance-measurement program, the *Guidebook for Developing a Transit Performance Measurement System* [**31**] provides useful information on more than 400 transit performance measures (including some for which levels of service have been developed) and on various means of measuring transit performance. The processes of developing customer satisfaction surveys and passenger environment surveys (a "secret shopper" approach to evaluating comfort-and-convenience factors) are summarized. Performance measures discussed in the guidebook cover the passenger, agency, community, and driver/vehicle points of view. Twelve case studies are presented in the guidebook on how agencies measure performance; 18 additional case studies are presented in a background document provided on an accompanying CD-ROM.

Application of Transit QOS Measures in Florida

Perk and Foreman (2001) [**32**] evaluated the process and results of the first year's application of the quality of service measures contained in the TCQSM by 17 metropolitan planning organizations (MPOs) in the state of Florida. Each MPO evaluated transit LOS in terms of service coverage, service frequency, hours of service, transit travel time versus auto travel time, passenger loading, and reliability.

The evaluation procedure balanced comprehensiveness (covering as much of the area as possible) with cost. Service coverage and transit-auto travel time were evaluated for the system. For the remaining measures, 6 to 10 major activity centers within the region, resulted in 30 or 90 combinations of trips between activity centers. Service frequency and hours of service were evaluated for all origin-destination (O-D) combinations. Passenger load and on-time performance data were collected for the 15 O-D combinations that had the highest volumes (total of all modes), as determined from the local transportation planning model. Transit travel times, hours of service, and frequencies were obtained from local transit schedules. The travel demand between centers was obtained from the local travel model. Field measurements were required to obtain reliability data and passenger loading data.

The authors point out that there were issues with the selection of major activity centers, including a general bias toward selecting for analysis those activity centers with the best existing transit service for analysis. The authors also found that the activity center selection method resulted in work ends of trips being over-represented and home ends of trips being under-represented

There were also various issues with the difficulty and cost of data collection (e.g., the validity of mixing field data on passenger loads and transit travel times with model estimates of travel times and demand for the computation of some of the level of service measures). Training to improve consistency and reduce wasted efforts was also necessary. There was a strong concern about the costs of collecting and processing the data without receiving additional state funding to cover those costs. MPO-estimated costs ranged from "negligible" to $50,000, with most in the $4,000-$5,000 range. The $50,000 cost reflects an MPO that waited until the last minute to start the work and ended up contracting the work out.

3.3 Bicyclist Perceptions of LOS

Researchers have used various methods to measure bicyclist satisfaction with the street environment. Methods have included field surveys (e.g., having volunteers ride a designated course), video laboratories, and web-based stated preference surveys. One researcher intercepted bicycle riders in the middle of their trip in the field.

Petritsch et al. [**33**] compared video lab ratings with field ratings of segment LOS and found they were similar.

Some researchers have asked bicyclists which factors are most important to the perception of quality of service. Other researchers have derived the factors by statistically fitting models of level of service to the bicyclist-reported level of service. Some researchers have used both methods.

Many researchers have fitted models that predict the mean level of service that would be reported by bicyclists. Some have fitted ordered cumulative logit models that predict the percentage of bicyclists who will report a given LOS grade. The final LOS grade is then the one for which at least 50% of the responses were equal to or greater than that LOS grade.

Some researchers (particularly the FDOT-sponsored research—See Landis for example) have defined LOS A as being the best and LOS F as being the worst. Others have defined LOS A as being "very satisfied" and LOS F as being "very unsatisfied" (see the Danish research reported by Jensen, below). Zolnick and Cromley [**34**] developed a bicycle LOS model based on the probability of bicycle/motor vehicle collision frequency and severity. One pair of researchers (see Stinson and Bhat below) sought to obtain measures of bicycle perceptions of quality of service by asking route choice questions. Their theory was that bicyclists will select the route that gives them the greatest satisfaction.

Most of the research has focused on predicting bicycle level of service for street segments between signalized intersections. A few research projects have focused on predicting the overall arterial street level of service.

An Arterial LOS Model Based on Field Surveys and Video Lab

Petritsch et al. [**35**] developed an arterial LOS model for bicyclists based on a mix of video laboratory and field surveys. LOS observations were obtained from 63 volunteers who rode the 20-mile course in Tampa, Florida, in November 2005. An LOS rating was obtained for each of the 12 sections of the course. A total of 700 LOS ratings were obtained. The average ratings for each section rated in the field ranged from LOS B to LOS E.

The volunteers identified bike lanes, traffic volume, pavement condition, and available space for bicyclists as their most important factors for rating section LOS. The recommended arterial LOS model for bicyclists is as follows:

$$\text{BLOS Arterial} = 0.797\ (\text{SegLOS}) + 0.131\ (\text{unsig/mile}) + 1.370 \qquad \text{(Eq. 5)}$$

Where

SegLOS = the segment level of service numerical rating ($A \le 1.5$, $B \le 2.5$, $C \le 3.5$, $D \le 4.5$, $E \le 5.5$)

Unsig/mile = Number of two-way stop controlled intersections per mile (arterial does not stop).

$$\text{SegLOS} = 0.507 * \ln(\text{Vol15/lane}) + 0.199\ \text{SPt}\ (1 + 10.38\ \text{HV})^2 + 7.066\ (1/\text{PC5})^2 + -0.005\ (\text{We})^2 + 0.760 \qquad \text{(Eq. 6)}$$

Where

Vol 15 = volume of directional traffic in 15-minute time period

L = total number of through lanes

SPt = effective speed limit (see below)

= 1.12ln(SPP -20) + 0.81

And SPP = Posted speed limit (mi/h)

HV = percentage of heavy vehicles

PC5 = FHWA's five point surface condition rating

We = average effective width of outside through lane

Petritsch [**36**] documented the video laboratory portion of the research. Seventy-five volunteers were shown video of eleven sections. The total viewing time for the video was 47 minutes. Comparison of the 615 LOS ratings by the video and the field participants found that the null hypothesis that there was no difference in the mean ratings between the field and video lab participants could not be rejected at the 5% probability of a Type I error (rejecting the null hypothesis when it is really true).

Segment LOS Models Based on Field Surveys or Video Lab

Jensen [**37**] showed 407 people video clips of 56 roadway segments (38 rural, 18 urban) in Denmark. A total of 7,724 LOS ratings were obtained for pedestrian LOS. Another 7,596 LOS ratings were obtained for bicycle LOS. A 6-point satisfaction scale was used (very satisfied, moderately satisfied, a little satisfied, a little dissatisfied, moderately dissatisfied, very dissatisfied). Jensen noted that walking against traffic, sounds other than traffic, weather, and pavement quality all affected perceptions of either bicycle or pedestrian LOS, but these variables were dropped from the model because they were not considered useful to the road administrators who would apply the models. Cumulative logit model forms were selected for both the bicycle and pedestrian LOS models. These models predicted the percentage of responses for each of the 6 levels of service. The single letter grade LOS for the facility was determined by the worst letter grade accounting for over 50% of the predicted responses for that letter grade and better (For example, if over 50% responded LOS B or better and less than 50% responded LOS A, then the segment LOS was B).

Landis et al. [**38**] documented a field survey of 60 bicyclist volunteers riding a 27-km (17-mi) course, in Orlando, Florida. The course included 21 intersections, of which 19 were signal controlled, 1 stop controlled, and 1 a roundabout. The volunteers ranged from 14 to 71 years of age (individuals 13 years and under were prohibited from participating because of safety concerns); 34 percent of the volunteers were female. Most of the volunteers were "experienced" bicycle riders (i.e., those riding more than 200 miles per year). Riders with over 1,000 miles per year of riding experience represented a disproportionate share of the volunteers.

The course consisted of roadways ranging from two to six lanes with average daily traffic (ADT) from 800 to 38,000 vehicles per day on the day of the survey. The percentage of trucks ranged from zero to 8.1. The posted speed limits ranged from 25 to 55 mph.

Participants were given a score card to carry with them and instructed to "circle the number that best describes how comfortable you feel traveling through the intersection" immediately after crossing each subject intersection. The researchers defined Level A for the participants as "the most safe or comfortable." Level F was defined for the participants as "the most unsafe or uncomfortable (or most hazardous)."

Videocameras were used to record (1) participant numbers and time at each intersection and (2) traffic conditions at the actual moment when the rider crossed the intersection. Machine road tube counters were used to collect volumes at the time of the survey. Turn-move counts were also collected on the day of the survey.

Participant starts were spaced so that bicycle-to-bicycle interference would not influence the LOS ratings.

The letter grades were converted to numerical values (e.g., A = 1, F = 6) (see Exhibit 32) and a hypothesis test was performed to determine if sex had a significant effect on the mean LOS ratings. The mean rating for the 20 female participants was 2.86. For the 39 male participants, the mean rating was slightly lower—2.83 (The lower rating implies better perceived LOS). A t-test indicated that this difference was not significant at the 5% Type I error level.

A second hypothesis test was made for delay. The 26 riders having to stop for the signal gave the intersections an average 2.93 rating, while the 33 not stopping rated the intersections 2.94 (the higher rating implied worse perceived LOS). This difference was also insignificant at the 5% Type I error level. Those stopping at a signal were delayed an average of 40 seconds.

A third test was for the effect of rider experience. The 55 experienced bicyclists reported an average LOS rating of 2.80. The four inexperienced cyclists reported an average LOS rating of 3.42 (the higher rating implied worse perceived LOS). This difference was found to be statistically significant. However, the four inexperienced cyclists' results were included with the experienced cyclists' results for the purpose of model development.

The level of service model is as follows:

$$LOS = -0.2144Wt + 0.0153CD + 0.0066(Vol15/L) + 4.1324 \quad \text{(Eq. 7)}$$

Where

LOS = perceived hazard of shared-roadway environment for bicyclists moving through the intersection.

Wt = total width of outside through lane and bike lane (if present).

CD = crossing distance, the width of the side street (including auxiliary lanes and median)

Vol15 = volume of directional traffic during a 15-minute time period.

L = total number of through lanes on the approach to the intersection.

The researchers reported a correlation coefficient (R-square) of 0.83 against the average repored LOS for each of 18 signalized intersections. The table below shows the author's proposed correspondence between LOS letter grade and the scores reported by the volunteers. The authors selected the breakpoints. They are not based on an analysis of the reported scores.

The lowest possible score that an individual could report was 1.00, so a preponderance of 1.00 responses was required for the average response to be less than 1.5. It was harder to get LOS A or LOS F than the other levels of service, because A and F require more agreement among the respondents than for the other levels of service.

Harkey, Reinfurt, and Knuiman [**39**] developed a model for estimating bicycle level of service, based on users' perceptions. The model, known as the Bicycle Compatibility Index (BCI), was designed to evaluate the ability of urban and suburban roadways to accommodate both motor vehicles and bicyclists. The study included 202 participants, ranging from 19 to 74 years of age; approximately 60 percent were male. The expertise level of the participants ranged from daily commuters to occasional recreational riders. The participants were surveyed in Olympia, Washington; Austin, Texas; and Chapel Hill, North Carolina. The study consisted of showing participants a series of stationary camera video clips taken from 67 sites in

- Eugene and Corvallis, Oregon;
- Cupertino, Palo Alto, Santa Clara, and San Jose, California;
- Gainesville, Florida;
- Madison, Wisconsin; and
- Raleigh and Durham, North Carolina.

Exhibit 32. Correspondence Between LOS Grade and LOS Numerical Score (Landis).

LOS	Model Score
A	≤ 1.5
B	> 1.5 and ≤ 2.5
C	> 2.5 and ≤ 3.5
D	> 3.5 and ≤ 4.5
E	> 4.5 and ≤ 5.5
F	> 5.5

The video clips showed various characteristics, including a range of curb lane widths, motor vehicle speeds, traffic volumes, and bicycle/paved shoulder widths.

Participants were asked to rate their comfort level based on a 6-point scale in the following categories: volume of traffic, speed of traffic, width or space available for bicyclists, and overall rating. In the end, eight variables were found to be significant in the BCI regression model:

- Number of lanes and direction of travel;
- Curb lane, bicycle lane, paved shoulder, parking lane, and gutter pan widths;
- Traffic volume;
- Speed limit and 85 percentile speed;
- Median type (including two-way left turn lane);
- Driveway density;
- Presence of sidewalks; and
- Type of roadside development.

Given that this research was done in a laboratory setting, the subjects could not take into account the comfort effects of pavement condition, crosswinds, and suction effects caused by high-speed trucks and buses. These factors consequently either do not show up or show up to a lesser extent in the BCI model.

Landis et al. [**40**] conducted a field survey of nearly 150 bicyclists who rode a 27-km (17-mile) course in Tampa, Florida. The subjects ranged in age between 13 and over 60 years of age, with 47 percent being female and 53 percent being male. The range of cycling experience was also broad—25 percent of the participants rode less than 322 km (200 miles) yearly to approximately 39 percent of the participants riding over 2,414 km (1,500 miles) yearly. In the study, participants were asked to evaluate the quality of the roadway links, not the intersections, on a 6-point scale (A to F) as to how well they were served as they traveled each segment. They were asked to only include conditions within or directly adjoining the right of way and to exclude aesthetics of the segments. Several significant factors were found to influence bicyclists' perceived quality of service or perceived hazard rating:

- Volume of directional traffic in 15-min period;
- Total number of through lanes;
- Posted speed limit;
- Percentage of heavy vehicles in the traffic stream;
- Trip generation intensity of the land adjoining the road segment;
- Effective frequency per mile of non-controlled vehicular access (e.g., driveway and on-street parking spaces);
- FHWA's five-point pavement surface condition rating; and
- Average effective width of the outside through lane.

Between the two bicycle quality of service studies, the laboratory study conducted by FHWA found very similar factors that influenced quality of service ratings. However, the field studies revealed variables that would be difficult to simulate in a laboratory setting, such as percentage of heavy vehicles and pavement surface condition. The participants in the field study rode alongside traffic and rated the percentage of heavy vehicles as one of the top important factors followed by the condition of the pavement. This comparison of data collection opportunities is the only one that can be made at this time for similar modes of travel, but may provide insight into the limitations of laboratory studies as compared with field studies.

Measuring LOS Through Route Choice

Stinson and Bhat [**41**] conducted a web-based stated-preference survey of 3,145 individuals. The individuals were recruited through announcements placed with 25 bicyclist-oriented listservers in the United States. Additional announcements were made to a few non-bicyclist-oriented e-mail lists. The sample of respondents was heavily weighted toward members of bicycling groups.

The authors identified 11 link and route attributes (each with multiple levels) for testing. To avoid participant overload, no more than four attributes were considered in any given survey instrument; thus, nine different instruments were required so as to cover the full range of attributes (and levels) of interest.

The respondent characteristics were as follows:

- 91% were experienced bicycle commuters.
- 22% were female.
- About 9% lived in rural areas, 39% lived in urban areas, the rest of the respondents lived in suburbs.

Stinson and Bhat identified travel time as the most important factor in choosing a route, followed by presence of a bicycle facility (striped lane or a separate path). Road class (arterial or local) was the third most important factor.

Stinson and Bhat obtained 34,459 observations of route choice and found that the best model of route choice considered the interactions between the bicyclist characteristics (e.g., age, residential location, and experience bicycling) and the route attributes. Stinson and Bhat noted however that the attributes of the route had a greater effect on route choice than the characteristics of the bicyclists themselves.

Models of Rural Road Bicycle LOS

Jones and Carlson [**42**] developed a rural bicycle compatibility index (RBCI) following a similar approach as that used to generate the FHWA BCI (see Harkey). They employed a web-based survey consisting of questions and thirty-two 30-second video clips.

The 30-second video clips were edited from 15-minute videos shot with image stabilization from a car moving 10 mph at a height 4.5 feet above the ground. Given that overtaking motor vehicle traffic tended to give wide clearance to the slow moving car on the shoulder, the video clips tended to show over-taking vehicles giving bicyclists more clearance than they would in reality. The clips were digitized in Windows Media Player compressed format for easy downloading by survey participants.

Participants for the web-based survey were recruited through letters to various bicycle groups, flyers distributed at popular recreational bicycling facilities, and personal recruiting by the authors.

A total of 101 participants (of which 56 were classified as experienced) successfully completed the survey. The experience level of the respondents was determined by induction from the responses to a few key questions. Slightly fewer than 20% of the respondents were female. None were under 18 years of age.

Three linear regression models (one for experienced riders, one for casual riders, and one for all riders) were fitted to the mean responses for each video clip. The best model included all bicyclists. The compatibility index in this model was a function of only two factors: shoulder width, and the volume of heavy vehicles traveling in the same direction as the bicyclist. The model had an R-square value of 0.67.

Jones and Carlson intentionally excluded pavement condition from the survey because of various data difficulties (including the difficulty of representing rough pavement in a video shot from a camera mounted on a car). All sites had relatively level grades, only two traffic lanes, and speed limits in excess of 50 mph.

Noel, Leclerc, and Lee-Goslin [**43**] recruited bicyclists already using various rural routes to participate in a survey of bicycle compatibility. A total of 200 participants were recruited at 24 sites. Bicyclists were stopped at the start of each test segment and asked to participate in the study. Those consenting were then interviewed to determine their characteristics (e.g., age and city of residence). Participants were given segment and junction rating cards to evaluate six sites on each segment. The cards were collected at the end of the segment and the participants were then asked about various potential factors affecting safety at the junctions.

The respondents were grouped into three experiential types: sport cyclists, moderate cyclists, and leisure cyclists. The survey found the following key factors affecting perceived comfort and safety (ranked by order of importance): riding space available to cyclist, traffic speed, presence of heavy vehicles, pavement conditions, presence of junctions, and finally, vertical profile of the route.

The proposed CRC index includes the following variables:

- Quality of Paved Shoulder;
- Size of Cycling Space;
- Auto Speed;
- Auto Flow;
- Truck Flow;
- Roadside Conditions (e.g., sand, gravel, and vegetation);
- Roadside Development;
- Vertical Profile;
- Longitudinal Visibility; and
- Major Intersections.

3.4 Pedestrian Perceptions of LOS

Researchers have used field intercept surveys and closed course surveys in the field to measure pedestrian perceptions of level of service. Some distributed questionnaires in the field to be returned later via the mail.

Various definitions of level of service have been developed (e.g., LOS A is defined as "best," "most safe," "very satisfied," or "excellent" depending on the researcher).

Some researchers have asked pedestrians to directly rate the level of service of a sidewalk or intersection, while others have sought to derive the LOS rating indirectly from the pedestrian's choice of which sidewalk and crosswalk to use.

Several researchers have focused on the intersection crossing environment. Most have looked at the sidewalk environment. A few have looked at mid-block crossings in between intersections.

None of the researchers have incorporated Americans with Disabilities Act (ADA) considerations in their measurement or prediction of pedestrian LOS. None of the research is specifically applicable to individuals with disabilities.

Intersection Crossing LOS Studies

Several studies focused on specific pedestrian facility types to identify the key variables that determine level of service there. Some focused on methods of determining LOS for pedestrians at crossing locations.

Hubbard, Awwad, and Bullock [**44**] developed a signalized intersection model for pedestrian LOS based on the percentage of pedestrian crossings affected by turning vehicles.

Chilukuri and Virkler [**45**] sought refinements to the HCM 2000 equation for pedestrian delay at signalized intersections, which assumes pedestrians arrive at an intersection randomly. They performed a study of coordinated signal intersections and found that pedestrian delays were significantly different at these locations than expected if arrivals were random. The authors concluded that the HCM pedestrian delay equation should be improved to incorporate the effects of signal coordination.

Clark et al. [**46**] developed a pedestrian LOS method based on discrete pedestrian crossing outcomes: non-conflicting, compromised, and failed. Their case study results found that the greatest incidence of failed and compromised pedestrian crossings was observed was a moderately high number of vehicular right turns were served by an exclusive right-turn lane that subtended an obtuse angle with a large turning radius.

Lee et al. [**47**] also looked at crossing LOS using a stated-preference survey. They found that the key determinants of LOS at signalized intersections were area occupancy, pedestrian flow, and walking speed. Similarly, Muraleetharan et al. [**48**] identified the factors that describe pedestrian LOS at crosswalks and found that the most important factor was the presence of turning vehicles. While confirming these findings, Petritsch et al. [**49**] provided additional insights into the critical factors that determine pedestrians' perceptions of LOS at signalized intersection crossings. They found that right-turn-on-red volumes for the street being crossed, permissive left turns from the street parallel to the crosswalk, motor vehicle volumes on the street being crossed, midblock 85 percentile speed of the vehicles on the street being crossed, the number of lanes being crossed, the pedestrian's delay, and the presence or absence of right-turn channelization islands were primary factors for pedestrians' LOS at intersections.

Sidewalk and Path LOS Studies

Other studies focused on measuring pedestrian LOS on sidewalks or paths. Analysis of the results of these studies suggests that the most important variables that determine pedestrian LOS—and therefore, the very definition of pedestrian LOS itself—change depending on the context.

As described in more detail under the bicycle LOS model section, Jensen [**50**] used video lab observations to develop a pedestrian segment LOS model for Denmark.

Bian et al. [**51**] conducted a sidewalk intercept survey to measure pedestrian perceptions of sidewalk LOS in Nanjing, China. A total of 501 people were interviewed on nine sidewalk segments. They identified lateral separation from traffic, motor vehicle volume and speed, bicycle volume and speed, pedestrian volume, obstructions, and driveway frequency as the factors influencing pedestrian LOS. They defined LOS 1 as "excellent," LOS 2 through 6 are "good," "average," "inferior," "poor," and "terrible," respectively. A linear regression model was fitted to the data to predict the mean LOS rating. The numerical score predicted by the model was converted to a letter grade using the following limits: LOS A <= 1.5, LOS B <= 2.5, LOS C <= 3.5, LOS D <= 4.5, LOS E <= 5.5.

Byrd and Sisiopiku [**52**] compared the more commonly accepted methods of determining pedestrian LOS for sidewalks, including the HCM 2000, Landis, Australian, and Trip Quality methods. The comparison found that it is possible to receive multiple LOS ratings for the same facility under the same conditions from these methods and the paper concludes that a combined model could be developed that synthesizes the quantitative and qualitative factors that affect pedestrian operations.

Muraleetharan and Hagiwara [**53**] used a stated preference survey to identify the variables most important to a pedestrian's perception of the utility of the walking environment. A revealed preference survey with 346 respondents was used to develop a utility model that predicts which route a pedestrian will prefer to walk. LOS A was assigned to the maximum computed utility among all of the sidewalks and crosswalks evaluated. LOS F was assigned to the lowest computed utility among all of the sidewalks and crosswalks evaluated.

Muraleetharan et al. [**48**] found that the "flow rate" is the most important factor that determines pedestrian LOS on sidewalks. Hummer et al. [**54**] studied pedestrian path operations and found that the path width, the number of meeting and passing events, and the presence of a centerline were the key variables that determined pedestrian path users' perceptions of quality of service. However, Patten et al. [**55**] noted that when paths are shared between pedestrians and bicyclists, estimating LOS for each user group and designing a new facility to the appropriate width and whether to separate these different users on the right-of-way becomes difficult. Sponsored by FHWA, they developed a bicycle LOS estimation method for shared-use paths to overcome these limitations by integrating a path user perception model with path operational models developed in the project's earlier phases. Petritsch et al. [**56**] found that traffic volumes, a sidewalk's adjacent roadway width, and the density of conflict points along it (e.g., the number of driveways) are the most important factors determining pedestrian LOS along urban arterials with sidewalks.

Taking a step back to revise the theoretical perspective on pedestrian LOS, Muraleetharan et al. [**57**] used conjoint analysis to develop a pedestrian LOS method based on total utility value. They found that total utility value can be used as an index of pedestrian LOS of sidewalks and crosswalks.

Sisiopiku et al. [**58**] reviewed recent research on pedestrian level of service. Their critique can be summed up as follows:

1. Non-HCM methods need to take into account the effect of platooning on pedestrian LOS.
2. All methods need to consider a variety of pedestrian groups. Different groups have different needs.

3. All methods need to be applicable to a full range of pedestrian facility types. Presence of sidewalk should not be a prerequisite.
4. The scale methodologies, although innovative, need further work to overcome problems with overlap of factors, small sample sizes, and nonlinear performance.
5. There is a need to consider a full and far broader range of factors for determining LOS.

Landis et al. [**59**] developed a method to measure pedestrian LOS, to aid in design of pedestrian accommodations on roadways, that is based on field measurements of pedestrian perceptions of quality of service.

The survey included 75 volunteer participants walking a 5-mile (8-km) looped course consisting of 48 directional segments. Traffic volumes ranged between 200 and 18,500 vehicles on the day of the survey. Heavy vehicles accounted for 3% or less of the traffic that day. Traffic running speeds ranged from 15 to 75 mph (25-125 km/h).

The participants were asked to evaluate each segment according to a 6-point (A to F) scale (see Exhibit 33) how safe/comfortable they felt as they traveled each segment. Level A was considered the most safe/comfortable (or least hazardous). Level F was considered the least safe/comfortable (or most hazardous).

Scoring fatigue was noticed as segment scores decreased as each participant walked the length of the course (Participant's expectations for the quality of the service drifted downward as they walked the course. Initial segments were rated more critically than later segments. It required about 2 hours to walk the length of the course). This problem was dealt with by walking people in opposite directions over the looped course and letting the fatigue effect cancel itself out through averaging of the responses.

After eliminating outliers, a total of 1,250 observations were available for analysis. A stepwise linear regression was performed. The resulting equation had an R-square value of 85%, but later researchers have noted that this value was for the ability of the model to predict the average LOS for a segment, not the actual LOS values reported by each individual participant.

Human factors are completely absent from the pedestrian LOS model. Age, sex, physical condition, experience, and residential location (i.e., urban, suburban, or rural) have no effect on the perceived LOS in this model. Crowding and intermodal conflicts with bicycles using the same facility are among the operational factors not included in the model. Grades, cross-slopes, and driveways are among the physical factors not included in the model.

$$\text{Ped LOS} = -1.2021 \ln (W_{ol} + W_l + f_p \times \%OSP + f_b \times W_b + f_{sw} \times W_s) + 0.253 \ln (Vol_{15}/L) + 0.0005\, SPD^2 + 5.3876 \qquad \text{(Eq. 8)}$$

Where

W_{ol} = Width of outside lane (feet)
W_l = Width of shoulder or bike lane (feet)
f_p = On-street parking effect coefficient (=0.20)
%OSP = Percent of segment with on-street parking
f_b = Buffer area barrier coefficient (=5.37 for trees spaced 20 feet on center)
W_b = Buffer width (distance between edge of pavement and sidewalk, feet)
f_{sw} = Sidewalk presence coefficient = 6 – 0.3Ws (3)
W_s = Width of sidewalk (feet)
Vol_{15} = Traffic count during a 15-minute period
L = total number of (through) lanes (for road or street)
SPD = Average running speed of motor vehicle traffic (mi/hr)

Use of Visual Simulation

Miller et al. [**60**] describes the use of computer-aided visualization methods for developing a scaling system for pedestrian level of service in suburban areas. A group of test subjects was presented with simulations (computer animations and still shots) of scenarios of improvements to a suburban intersection at an arterial. The subjects were asked to rate each option from A (best) to E (worst) and also to give a numerical score from 1 to 75. These ratings were compared with a set of LOS ratings derived from a scale in which points were assigned based on various intersection characteristics: median type, traffic control, crosswalks, and speed limits. The results of the experiment led to a substantial revision of the scale ranges that correspond to specific levels of service. The authors concluded that, although visualization cannot replace real-world experience, it can be an appropriate tool for site-specific planning. The methods discussed are ". . . inexpensive, practical, and original ways of validating a scale that help ensure that the pedestrian environment is not unnecessarily compromised, especially on automobile-dominated arterials."

Midblock Crossing LOS Studies

Chu and Baltes [**61**] developed a LOS methodology for pedestrians crossing streets at mid-block locations.

Exhibit 33. LOS Categories.

LOS	Model Score
A	≤ 1.5
B	> 1.5 and ≤ 2.5
C	> 2.5 and ≤ 3.5
D	> 3.5 and ≤ 4.5
E	> 4.5 and ≤ 5.5
F	> 5.5

Thirty-three mid-block locations in Tampa and St. Petersburg were identified to be included in the study. A total of 96 people were hired by a local temp-worker agency to test the mid-block crossings. They ranged in age from 18 to 77 years with a mean of 42.7 years of age. Sixty-eight percent of the participants were female and 32 percent were male.

The participants were bused to each site and asked to observe mid-block crossings for 3-minute periods and then rate the difficulty of crossing on a six-point scale (A to F). Crossing difficulty was defined as the risk of being hit by a vehicle, the amount of time to wait for a suitable gap in traffic, presence of a median or other refuge, parked cars, lack of an acceptable (wide enough) traffic gap, or anything else that might affect crossing safety in determining the crossing difficulty. It was stressed to the participants to only consider their crossing difficulty, not for others that might cross the roadway. A total of 767 observations were made. Results of the study showed that the level of crossing difficulty tended to increase with the width of painted medians, signal spacing, and turning movements, and that the presence of pedestrian signals lowered the perception of crossing difficulty. The presence of pedestrian signals and cycle length were also shown to be statistically significant. The final linear regression model had an R-square value of 0.34 and contained 15 variables relating to traffic volumes, turning volumes, age of pedestrian, average vehicle speed, crossing width, presence of pedestrian signal, cycle length, and signal spacing.

Chu, Guttenplan, and Baltes [**62**] placed 86 people at 48 intersection and mid-block locations and asked them to identify one of six routes they might take to cross the street. They obtained a total of 1,028 observations of 4,334 cases. They fitted a 2-level nested logit model to the survey responses. The first level predicted whether they would cross at an intersection or cross mid-block. The lower level then predicted which of various mid-block crossing routes they might pick. The significant explanatory factors were starting or ending point of trip, walking distance, crosswalk marking, and presence of traffic or pedestrian signal. Less significant factors included in the model were traffic volume and shoulder/bike lane width. Delay at the signal was not an explicit factor. The presence of a signal positively encouraged crossings at the intersection.

3.5 Multimodal LOS Research

Recent work on developing a method to estimate multi-modal LOS appears to wrestle with the issue of defining what LOS means in a multi-modal context. Several of these studies are working to establish a “common denominator” that can be used to compare the performance of different modes without unintentionally favoring one mode over the others. Winters and Tucker [**63**] reported on their work for the Florida Department of Transportation (FDOT) to develop a new approach to assess levels of service for automobile, bicycle, pedestrian, and transit modes of travel equally. To even the playing field among modes, they postulated a hierarchy of transportation user needs based on Abraham Maslow’s theory of personality and behavior. This transportation theory would consist of five levels: safety and security (the most basic need), time, social acceptance, cost, and comfort and convenience (the least basic need). Perone et al. [**64**] provide an update to this FDOT work in their final project report. Their final multi-modal model is based on the work of Maslow as well as Alderfer and his Existence, Relatedness and Growth (ERG) Theory. The project provides evidence for the existence of such a hierarchy in which most participants chose Existence over Relatedness over Growth needs and found that a lower motivator need not be substantially satisfied before one can more onto higher motivators.

Dissatisfied with inadequacies of auto-based (i.e., HCM) and other multi-modal measures of LOS for project-level environmental impact reviews, Hiatt [**65**] reports on the City of San Francisco’s efforts to develop an alternative method for use in that city’s urban, multi-modal context. The paper discusses a proposed alternative to modal-based LOS measures that calculates automobile trips generated that would vary by land use typology and parking supply, and reflect expected mode shifts associated with projects such as bicycle or transit lanes.

Winters et al. [**66**] looked at various methods for achieving comparability of LOS significance across modes. They identified the issue of different letter grades implying “traveler satisfaction” for the various modes. LOS D for highway facilities is considered satisfactory by many public agencies for facility planning purposes. However, LOS D for bicycles may be a facility that only the hardiest bicyclists dare use. LOS D may not be a satisfactory level of service for planning bicycle facilities.

The authors conducted a literature review and then developed various options for reconciling the meaning of LOS across modes to an advisory panel of stakeholders consisting of potential technical users of the LOS methodology for state and local agency facility planning purposes.

The authors looked at how the various modal measures of LOS addressed different degrees of travelers’ needs. Some, like FDOT’s bicycle and pedestrian LOS measures are based on travelers’ perception of safety, which is a higher priority need than “convenience” which is implicit in the auto LOS measure of speed.

They suggested offsetting the scales against some standard of traveler satisfaction, i.e., using a sliding scale. LOS D is the threshold of acceptability for auto, but LOS C is the threshold of acceptability for bicycles. The advisory panel accepted (with reservations) this slide rule method, but recommended that additional data be acquired for identifying common denominators across modes for level of service.

Crider, Burden, and Han [**67**] developed a conceptual framework for the assessment of multimodal LOS at intersections and bus stops for the transit, bicycle, and pedestrian modes. For transit, a bus stop LOS measure based on frequency and pedestrian accessibility was recommended. For bicycles and pedestrians, intersection LOS measures based on conflicts, exposure, and delay to through movements were recommended. Various techniques for surveying traveler perceptions were considered and a selected set of techniques was recommended.

Dowling [**68**] developed a methodology for assessing multimodal corridor level of service involving parallel facilities. The methodology generally relied on existing FDOT methods for estimating facility LOS and created new LOS measures to address aspects of corridor LOS not covered by current methods. New LOS measures included difficulty of crossing of freeway LOS, freeway HOV lane LOS, rail LOS, off-street bike/pedestrian path LOS, and a congestion-based measure of auto LOS (i.e., the ratio of congested speed to free-flow speed).

Phillips, Karachepone, and Landis [**69**] documented the results of a project to develop planning analysis tools for estimating level of service for transit, pedestrian, and bicycle modes. This research built on prior research by Sprinkle Consulting and Kittelson & Associates and was adapted for use in the Florida Quality/Level of Service Handbook.

The Phillips, Karachepone, and Landis report defined Quality of Service as "The overall measure or perceived performance of service from the passenger's or user's point of view." The report defined Level of Service as "A range of six designated ranges of values for a particular aspect of service, graded from "A" (best) to "F" (worst) based on a user's perception." It defined Performance Measures as "A quantitative or qualitative factor used to evaluate a particular aspect of service." The distinction between "service measures" and "performance measures" was that service measures represented only the passenger or user's point of view, while performance measures could consider a broader range of perspectives, especially those of the public agency.

Guttenplan et al. [**70**] discussed methods developed by FDOT to determine level of service to through vehicles, scheduled fixed-route bus users, pedestrians, and bicyclists on arterials. FDOT was concerned that the HCM assessment of arterial LOS focuses primarily on the automobile; LOS designations for pedestrians and bicycles are based primarily on facility crowding. Recent research, however, has found that quality of service for pedestrians and bicyclists depends more on lateral separation of the mode, motorized vehicle volumes and speeds, and transit frequency of service.

This paper presented the methods used by FDOT to calculate LOS for bicycles, pedestrians, and transit. For each mode, a score is computed using various characteristics of the roadway and traffic; LOS thresholds are used to transform the scores into LOS measures. Bicycle LOS depends primarily on effective width of the outside through lane (including bicycle lane width) and the volume of motorized vehicles. Pedestrian LOS depends on sidewalk presence, roadway widths, separation from traffic, and vehicle speeds and volumes. Transit LOS depends on service frequency, adjusted for pedestrian LOS and hours of service per day.

The methods described in the paper are primarily segment-based; additional research is under way to expand the applicability of the method (e.g., to area wide and point-level analyses). Separate LOS measures are provided for the different modes; but FDOT does not provide a single LOS measure that combines all modes because doing so could mask the effect of less-used modes. A key feature of the method is that it captures interactions between modes, including the interactions of pedestrians and transit.

Guttenplan et al. [**71**] describes the development of a multimodal areawide LOS methodology based on the FDOT Q/LOS Handbook procedures for individual facilities and modes. The steps of the methodology are

1. Define major modal facilities within study area.
2. Determine percentage of households and employment located within service areas of each major modal facility. The percentage of households and employment served by the major modal facilities sets the ceiling for the best possible areawide LOS for the mode.
3. Determine modal LOS for each major modal facility.
4. Compute mean modal LOS across all major modal facilities in the study area.
5. Select the lower of mean modal facility LOS or the percentage households and employment served LOS value.

CHAPTER 4

Data Collection

The literature review found that various methods have been used to measure traveler perceptions of quality of service (i.e., field surveys, video laboratory surveys, simulator surveys, telephone surveys, and web surveys). The literature review revealed the wide range of customer satisfaction measurements used and the wide range of variables that researchers had determined to be critical for predicting or measuring traveler perceptions of quality of service. Some of the differences could be attributed to differences in survey methods. Other differences could be attributed to differences in the situations to which the survey participants were exposed. Still other differences could be attributed to differences in how quality of service was defined (or left undefined) for the participants. In addition, all surveys were limited to a single metropolitan region, so it was not possible to rule out the potential effects of geographic location on the reported LOS models.

The objective of the data collection task was, therefore, to develop and execute a set of quality of service surveys that could be uniformly and consistently implemented across all modes and in several different metropolitan areas of the United States.

All prior quality of service surveys had been limited to a single site in a single urban area. One of the major purposes of the new data collection under NCHRP Project 3-70 was to gather data using a consistent method across multiple urban areas to determine if LOS perceptions vary significantly across urban areas of the United States.

The data collection task of this project was conducted in two phases. Various data collection methods were pilot tested during Phase 1. The data collection effort for the project was completed in Phase 2.

4.1 Selection of QOS Survey Method

Several different methods have been used in the literature to measure traveler perceptions of satisfaction. These methods include traveler intercept surveys, field laboratory studies, and video laboratory studies. Introductory material on customer satisfaction survey techniques can be found in Trochim [**72**].

- **Traveler Intercept Surveys** directly measure the LOS perceptions of actual travelers making real trips. These surveys intercept travelers mid-trip and either orally interview them on the spot or give them a postcard to report their LOS perceptions at a convenient time after they have completed their trip. The Noel, Leclerc, and Gosselin [**73**] study of rural bicycle LOS used this method to measure bicycle LOS on rural roads.
- **Field Laboratory Studies** recruit subjects (paid or unpaid volunteers) to travel over a fixed course in the field and report their LOS perceptions at strategic points along the course. The "Bike for Science" and "Walk for Science" studies by Landis et al. [**74**] [**75**] are examples of this approach to measuring traveler perceptions of level of service.
- **Video Laboratory Studies** show recruited subjects film clips of various street situations in a video laboratory setting. The Pecheux et al. [**76**] and Sutaria and Haynes studies [**77**] for intersection level of service are two examples of this approach to measuring traveler perceptions of level of service.

The level of service research to date is split fairly evenly between the use of field laboratory settings and video laboratory settings for measuring traveler perceptions of level of service (see Exhibit 34). Traveler intercept surveys have been used by a few researchers to measure traveler LOS.

Traveler Intercept Surveys, Field Laboratory Studies, and Video Laboratories Studies each have their relative strengths and weaknesses (see Exhibit 35).

The traveler intercept surveys can gather responses from large numbers of individuals, but only for the particular trip that they made on the facility—the researcher obtains only one data point for each individual responding to the survey.

Exhibit 34. Traveler Perception Survey Methods in the Literature.

Research Team	Data Collection Method	LOS Model
Auto		
Hall, Wakefield, and Kaisy [**78**]	Focus Group Discussions	Freeway
Pecheux et al.**79**]	Video Laboratory (100 subjects)	Signalized Intersection
Sutaria and Haynes [**80**]	Video Laboratory (310 subjects)	Signalized Intersection
Nakamura, Suzuki, and Ryu [**81**]	Field Laboratory (24 subjects)	Rural Road
Colman [**82**]	Field Laboratory (50 subjects)	Urban Street
Transit		
Morpace [**83**]	Traveler Intercept Survey on-board vehicle	Route
Bicycle		
Landis et al. [**84**]	Field Laboratory (60 subjects)	Intersection
Harkey, Reinfurt, and Knuiman [**85**]	Video Laboratory (202 subjects)	Segment
Jones and Carlson [**86**]	Video Lab. Over Web (101 subjects)	Rural Road
Noel et al. [**87**]	Traveler Intercept Survey (200 subjects)	Rural Road
Landis, Vattikuti, and Brannick [**88**]	Field Laboratory (150 subjects)	Segment
Stinson and Bhat [**89**]	Video Lab. Over Web (3,145 subjects)	Segment
Pedestrian		
Miller, Bigelow, and Garber [**90**]	Simulated Video Lab	Intersection
Landis et al. [**91**]	Field Laboratory (75 subjects)	Segment
Chu and Baltes [**92**]	Field Laboratory (96 subjects)	Mid-block Crossings
Nadeir and Raman [**93**]	3-D Video Simulator	Segment

Traveler intercept surveys may be the most realistic in that travelers are in an actual trip-making situation; however, the particular method used to intercept travelers may bias the results, especially, if the traveler is detained a long time or if certain "hard to stop" travelers are not interviewed or given a post card. Also, there may not be enough travelers on truly poor road sections to survey.

Although the initial investment for traveler intercept surveys, and the cost per each subject are quite low, the cost per data point obtained (i.e., the product of the number of individuals surveyed and the number of situations they were exposed to) is higher than for the other data collection methods (if one considers only the marginal costs and ignores the high initial investment costs of the video laboratory).

The field laboratory studies also have low initial investment costs, and they have the lowest cost per data point obtained. However, they are expensive to set up for a given site and have a high cost per subject. Each subject, however, is exposed to a wide variety of situations in the field, so this method generates numerous data points per individual.

Field laboratory studies are realistic in that they expose the volunteer subjects to the full sensory experience (all five senses) of field conditions; however, because there is no penalty for arriving late at one's appointment or job the realism of the trip experience is questionable.

Video laboratory studies require an initial investment to create the video clips. If there is doubt about the ability of the video to capture all of the factors affecting a traveler's perception of LOS, then there is also an added expense for calibration of the video lab LOS results to the field.

Once the video clip has been assembled and calibrated, the cost per data point obtained is lower than that for traveler intercept surveys, but higher than for field laboratory studies. The cost per subject though is higher than for the traveler intercept surveys, because video labs typically test fewer subjects than would be found in an intercept survey.

The video labs and field laboratories test fewer subjects than the traveler intercept surveys; however, both laboratory studies can expose single subjects to multiple conditions, thus enabling researchers to distinguish between a single subject's reaction to a range of situations and differences in multiple subjects' reactions to the same situation. This capability (highly valuable for model building) is not available in the traveler intercept surveys.

The traveler intercept surveys are better for general model validation than for detailed model development. Video laboratory and field laboratory studies are better for model development because they give researchers more control over the variability of the results.

Field surveys of traveler satisfaction, such as the FDOT/Sprinkle "Walk For Science" surveys, come closest to the real world experience of travelers while controlling for the range of conditions they experience. However, this survey method is expensive and prone to agency liability problems (caused by exposing the participants to specified field conditions they might not otherwise attempt on their own). Conducting field surveys of traveler satisfaction would have cost $150,000 per mode per site to set up and conduct. For four modes and four cities, the data collection cost alone would have exceeded the entire research project grant. Thus field surveys were deemed infeasible.

Exhibit 35. Validation Data Collection Options.

Survey Type	Strengths	Weaknesses	Cost
Traveler Intercept Surveys: Surveyors stop people mid-trip to distribute post cards or conduct survey.	1. Most realistic of all methods. Only method that captures traveler's response while making a real trip. 2. Can test for effects of travel time, wait time, and cost in combination with physical characteristics of facility.	1. No control over subject's exposure to facility conditions. 2. Limited information on extent of subject's exposure to facility. 3. Can't test the same person's response to conditions other than those of specific trip. 4. People don't like to be interrupted while traveling, which may bias results. 5. Can't sample extreme conditions. 6. Modal sample sizes depend on volumes. Bicycles are difficult to sample adequately.	**Initial Investment:** $20,000 to pilot-test intercept methods. **Data Collection:** $15,000 per site for four modes. $60 per data point (not counting initial investment)
Field Laboratory: Paid or unpaid volunteers travel specified course.	1. Second most realistic of survey types. It puts subjects in realistic physical situations, lacking only the realism of making the actual trip for an actual purpose (such as going to work). 2. Good control on subject exposure to facility.	1. Potential liability for accidents. 2. Can't expose subjects to conditions not present in community or at time of test, particularly true for surveys using weekend volunteers. 3. Because subjects are not actually going anywhere the usual factors that influence trip-making behavior (travel time, wait time, and cost) cannot be reliably included or ruled out. 4. Unpaid volunteers are self-selected.	**Initial Investment:** $-0- because method is well tested. **Data Collection:** $150,000 per site per mode. $10-$25 per data point. (not counting initial investment)
Video Laboratory: Selected subjects shown video clips in laboratory setting.	1. Controlled exposure of subjects to audio-visual aspects of travel. 2. Little liability exposure. 3. Can expose subjects to wide range of conditions and time periods, thus enabling more in-depth analysis for each individual.	1. Not as realistic as simulator or field tests. Some important aspects of trip are excluded (e.g., pavement condition and rumble and back draft from trucks passing the subject). 2. Factors that influence trip-making behavior (e.g., travel time, wait time, and cost) cannot be reliably tested. 3. Needs calibration/validation against field conditions. 4. Not realistic for Transit.	**Initial Investment:** $55,000 to develop videos for three modes. Another $125,000 to calibrate to field. **Data Collection:** $64,000 per lab site for three modes. $42 per data point (not counting initial investment)

Compared with the "Walk For Science" field surveys, traveler intercept surveys sacrifice the ability to "control" the range of physical conditions to which the participants are exposed. In addition, the travelers are self-selected (i.e., they would not be there to be intercepted, if it were not already their preferred mode and route). Nevertheless, among the remaining feasible survey methods, traveler intercept surveys were the best method for gathering transit rider quality of service perceptions. They were within the budget range of the research grant and travelers were exposed to the full physical experience of the transit experience.

The traveler intercept survey method however was problematic for auto and bicycle LOS because it is difficult to intercept auto drivers and bicyclists on the street without adversely affecting their perception of the quality of service. Consequently it was determined that this survey method could not be used for the auto or bicycle modes.

This left video lab surveys as the best remaining method for surveying auto and bicycle level of service, because of its relatively low cost, the ability to control the environment to which each participant was exposed, the elimination of research agency liability exposure, and the ability to expose different people from different geographic areas to the same perceived street environment.

Although it would have been feasible to use a traveler intercept survey method for pedestrians, the video lab survey method was considered superior because it would enable the team to expose survey participants to a controlled wider range of physical conditions (including lack of sidewalk) that would not be easy to find in the field.

The video lab approach also enabled testing of the significance of demographics and metropolitan area on the perceptions of quality of service.

4.2 Phase I Data Collection (Pilot Studies)

During Phase I, the video lab method for gathering traveler quality of service ratings was developed and tested. A video lab approach for measuring auto level of service was tested by George Mason University in Virginia. Sprinkle Consulting tested a similar video laboratory approach for pedestrian level of service in Florida.

For the transit mode, a rider intercept approach for transit level of service was tested in three metropolitan areas of the United States (Ft. Lauderdale, Florida; Washington, DC; and Portland, Oregon). A total of 1,320 people were surveyed, and 2,535 observations of quality of service were gathered during Phase 1. Exhibit 36 provides key statistics on this Phase 1 data collection effort.

The data gathered for each mode are summarized below.

Auto: Fourteen video clips were developed and shown to 75 research subjects in the Washington D.C. metropolitan area. The results showed that a single factor, average travel speed, explained 64% of the variation in LOS ratings reported by the laboratory participants.

Comparison of the video lab perceptions to field perceptions of LOS identified the same key factor influencing LOS in the field (speed) as was found in the video lab. The correlation of the lesser factors to LOS varied between the field and the lab. The influence of other operational factors (signals and stops), design, maintenance, and aesthetics on LOS was less pronounced in the field than in the lab. The one significant exception was pavement condition, which had a stronger influence in the field than in the lab (as expected, given that the video gives only a visual input on pavement condition, while the field gives both visual and tactile inputs).

The researchers noted that the limited number of video clips in the video library for Phase 1 resulted in some factors being spuriously correlated (for example: speed and the presence of trees). This makes it difficult to build statistically robust models of LOS from the video laboratory data that accurately reflect the separate contribution of each correlated factor to a person's perceived LOS. Thus for Phase 2 it was recommended that the video clip library be expanded to include a wider range of cases.

Transit: The Phase 1 data collection effort obtained a large amount of data (1,170 observations) for three urban areas (Miami; Portland; and Washington, DC). The research team noted that the specific routes surveyed in those metropolitan areas for Phase 1 did not exhibit significant crowding at the dates and times of the surveys. This gap in the transit data caused crowding to drop out as a significant explanatory factor of transit LOS. Therefore it was recommended that a few additional surveys be conducted in Phase 2 of more crowded bus routes with standees in one of the metropolitan areas.

Pedestrian: Eight video clips were developed and shown to 45 participants in one metropolitan area (Sarasota, FL). These clips, however, did not cover a very wide range of LOS conditions (most being LOS C according to the FDOT method). Thus the research team recommended that additional video clips of a wider range of conditions be obtained for Phase 2.

Bicycle: No data collection was performed for bicycles in Phase 1, so an entire new video clip library was developed for Phase 2.

4.3 Development of Video Clips

Auto Video Clips

Based on findings from Phase I, the most influential factors to driver perceived level of service were selected by the research team. These included in no particular order

- Presence of median (Yes/No);
- Landscaping (Yes/No);
- Progression (no progression is stopped at more than 50% of signals);
- Posted speed (surrogate for arterial type); and
- LOS depicted in clip using HCM methods.

Exhibit 36. Phase 1 Data Collection Efforts.

Contractor	Mode	Method	Number of Metro. Areas	Persons	Data Points	Cost
GMU	Auto	Video Lab	1	75	975	$ 75,660
KAI	Transit	Field Intercept	3	1,170	1,170	$ 40,000
SCI	Ped	Video Lab	1	45	360	$ 30,500
Total Phase I			5	1,290	2,505	$ 146,160

GMU = George Mason University, KAI = Kittelson Associates, SCI = Sprinkle Consulting
A data point is defined as one person providing an LOS rating for a single facility condition. Thus a person watching 10 video clips generates 10 data points.

These factors were chosen by the research team, with input from the project panel, as those factors that could most easily be measured by engineers, those that were most important to drivers (as determined in previous studies and Phase I of the study), and those that could be captured in the field through videotaping.

Arterials were selected in the Washington, DC, metropolitan area that captured the required combination of conditions. As noted, some of the video clips were developed in Phase I of the study; an additional subset of video clips were developed by GMU in the summer/fall of 2005 in preparation of the data collection in the summer of 2006.

As with the Phase I pilot test, videos were created for daylight conditions only. Taping was also limited to clear days without precipitation, and for the most part, snow is not a feature on the majority of tapes.

In order to film the video clips, the following testing materials were used:

- Vehicle;
- Two video cameras (one to capture the driver's perspective and one to capture the speedometer); and
- Two camera tripods.

Standard vehicles (e.g., station wagons, sedans, and, in a few cases, small sports utility vehicles) were used for videotaping. Vehicles were rented from the GMU motor pool so as to standardize the vehicle set up and ride quality.

Researchers set up two cameras and the GPS unit when they arrived at the vehicle rental location. A professional JVC digital videocamera, loaned to the project by the GMU Media Laboratory, was used to capture the roadway scene from the driver perspective (typically a full windshield view and peripheral views of the roadside) and a palm-sized digital videocamera was used to capture the speedometer view.

After the initial taping runs took place, the individual clips needed to be extracted. Based on the requirement of 1/2-mile on urban arterials (as determined through Phase I efforts), these clips were developed. The emphasis was on extracting segments from the videos that met several criteria including:

After the videotaping took place, the researchers used the following to extract the videos:

- Video editing decks available in the GMU Media Laboratory;
- Adobe Premiere 9.0 video editing software;
- Microsoft MapPoint;
- Microsoft Excel;
- Original mini-Digital Videos (DV) created in the field; and
- Mini-DV player.

In order to depict a consistent scene to study participants, it was necessary to identify video clips that had consistent cross section. For example, efforts were made to identify sections of video in which the roadway width did not change during the drive or that the sidewalk conditions were relatively consistent. Using a portable mini-DV player, students identified the portions of roadway to be made into a clip based on criteria such as arterial type, consistent cross section, lane position, and speed limit. After the general area of the clip was identified, the researchers turned to Microsoft MapPoint.

After each section of roadway was identified, individual clips needed to be made. The video feed needed to be synchronized with the speedometer feed. This was done using the mini-DV player and the time stamps on it. The field team had announced the run orally while the videocameras were filming the study arterials. The researcher's voice was used to synchronize time stamps of the videocameras. Then, the researchers found the location of the beginning and end of the proposed clip and determined the tape length equivalencies for the two video feeds, for example 1 minute 6 seconds into the tape was when the voice was first heard on tape 1, 1 minute 20 seconds into the tape was when the voice was first heard on tape 2.

After identifying the time stamps for both the road video and the speedometer, the team began editing using the video editing equipment available at GMU's Media Laboratory to cut the clips and merge the speedometer video into the lower righthand corner of the video screen to simulate driving the vehicle. Adobe Premiere 9.0 was used to merge the two videos and create each clip. Once all the clips were made, transitions were put in between each clip on the final media to help proctors and participants identify each clip (for example, Clip #3) using the same software package. Then, the clips were merged and burned onto DVDs.

Exhibit 37 summarizes the characteristics of the auto clips.

Bicycle Video Clips

Bicyclists are among the most vulnerable of travellers and are affected by a broader variety of traffic and roadway environmental factors (stimuli) than that of the motorized modes. Consequently, when collecting data and modeling perceptions, care must be taken to capture this sensitivity to the many environmental factors.

Previous research, model development, and nationwide deployment of non-motorized LOS mode models have demonstrated that field-based studies are desirable to capture accurate perceptions of bicyclists. Such studies place the participants in typical real-life situations and capture the participants' response to the host of stimuli present in roadway environments affecting bicyclists. However, field studies can be expensive and, depending on the range of conditions and variables being explored, represent the highest risk for participants of any method.

Exhibit 37. Summary of Auto Clip Characteristics.

Clip #	Clip Distance (miles)	Street Name	HCM Class	LOS as per HCM	Number of Through Lanes	Presence of Median	Total Travel Time (seconds)	Space Mean Speed	PED on sidewalk	# Stops (below 5 mph)	Total # of Signals	Pres. Of Ex. LT Lane - Signals	Pres. Of Rt Turn Lane- Signals	Tree Presence	Average Lane Width (ft)	Width of Median (ft)	Rigth Shoulder width (ft)	Left Shoulder Width (ft)	Width of parking lane (ft)	Width of sidewalk (ft)	Separation from right-of-way to sidewalk (ft)	Width of bike lane (ft)
1	0.50	Rt 234	1	1	3	3	119	15.1	0	1	2	1	1	2	12	54	0	3	0	4	3	0
2	0.46	Gallows Road	3	6	2	3	48	34.5	0	0	3	1	1	2	13	4	0	0	0	4	3	0
5	0.50	Wilson Blvd	3	5	2	3	60	30.0	2	0	3	1	1	1	14	0	0	0	7	10	0	5
6	0.43	Clarendon	3	3	2	1	87	18.3	2	1	2	1	0	1	14	0	0	0	7	4	0	0
7	0.48	Wilson Blvd	3	4	2	1	86	20.1	2	0	3	1	0	1	14	0	0	0	7	10	0	5
8	0.49	Wilson Blvd	3	2	2	1	130	13.6	2	2	5	1	1	1	12	0	0	0	8	14	0	6
10	0.53	Washington Blvd	3	3	1	0	113	16.9	2	2	3	0	0	3	12	0	0	0	8	6	0	0
12	0.47	Wilson Blvd	3	3	2	0	118	14.3	0	2	2	0	0	1	11	0	0	0	8	11	5	0
13	0.50	Washington Blvd	3	5	1	0	71	25.4	1	0	1	0	0	3	12	0	0	0	8	6	0	0
14	0.50	Glebe Road	2	1	3	3	161	11.2	2	3	3	1	1	1	11	4	0	0	0	8	0	0
15	0.50	Glebe Road	2	1	3	3	229	7.9	2	3	3	1	1	1	11	4	0	0	0	8	0	0
16	0.55	Fairfax Drive	3	1	2	3	163	12.1	2	4	4	1	1	1	11	10	0	0	8	16	0	5
19	0.52	23rd St	4	4	2	0	116	16.1	2	3	8	0	0	2	10	0	0	0	7	6	5	0
20	0.55	Rt 50	1	2	2	3	122	16.2	2	1	2	1	0	1	11	17	8	2	0	0	0	0
21	0.50	Rt 50	1	2	2	3	89	20.2	2	2	3	1	1	2	11	17	8	2	0	0	0	0
23	0.54	M St	4	2	2	0	243	8.0	2	3	8	0	0	1	10	0	0	0	10	10	0	0
25	0.54	M St	4	3	2	0	179	10.9	2	2	8	0	0	1	10	0	0	0	10	10	0	0
29	0.50	Rt 234	2	4	3	3	79	22.8	0	1	3	1	1	2	12	54	0	3	0	0	0	0
30	0.55	M St	4	1	2	0	298	6.6	2	8	8	0	0	1	10	0	0	0	10	10	0	0
31	0.50	M St	4	1	2	0	471	3.8	2	9	8	0	0	1	10	0	0	0	10	10	0	0
51	0.44	M St	4	1	2	0	240	6.5	2	4	9	0	0	1	10	0	0	0	10	10	0	0
52	0.41	M St	4	2	2	0	186	7.9	2	3	7	0	0	1	10	0	0	0	10	10	0	0
53	0.60	Prosperity	2	3	2	3	121	18.5	0	1	2	1	1	2	12	15	0	0	0	4	4	0
54	0.60	Lee Hwy	2	4	2	2	93	24.5	0	2	4	1	1	3	12	14	4	4	0	4	10	0
55	0.45	Braddock Rd	2	1	2	3	128	12.7	0	1	1	1	1	3	12	15	0	0	0	6	0	0
56	0.50	Sunset Hills Rd	2	4	2	3	77	23.1	0	1	1	1	0	3	12	8	0	0	0	0	0	0
57	0.61	Sunset Hills Rd	2	3	2	0	129	17.4	0	2	2	0	0	3	12	0	0	0	0	4	2	0
58	0.60	Sunrise Valley Rd	2	1	2	3	144	11.2	0	1	3	1	0	3	12	10	0	0	0	3	4	0
59	0.61	Sunset Hills Rd	2	1	2	0	182	12.1	0	3	2	0	0	3	12	0	0	0	0	4	4	0
60	0.50	Lee Hwy	2	2	2	2	120	15.0	0	1	3	1	0	1	12	14	0	0	0	4	4	0
61	0.70	Rt 50	1	4	3	0	91	27.7	0	1	3	1	0	3	12	0	0	0	0	0	0	0
62	0.50	Rt 50	1	5	3	0	49	36.7	0	0	2	1	0	3	12	0	0	0	0	0	0	0
63	0.50	Rt 50	1	6	2	3	53	41.9	0	0	2	1	1	3	12	6	4	4	0	0	0	0
64	0.50	Rt 50	1	2	2	3	92	19.6	0	1	3	1	0	3	12	6	0	0	0	0	0	0
65	0.50	Lee Hwy	2	6	2	2	50	36.0	0	0	3	1	0	2	12	14	0	0	0	0	0	0

Video simulation, however, potentially provides some significant advantages to real-time field surveys, particularly if the "moving camera" approach is used. The moving camera perspective gives the video simulation a greater reflection of reality as opposed to the stationary camera. Moving camera simulation also allows for a wider range of geographic participants and the testing of a greater range of variables, particularly the potentially hazardous higher truck volumes and the high frequencies of driveway/curb cut common in jurisdictions with minimal roadway access management practices. Finally, moving camera (video) simulation, if done based on lessons learned through previous bicycle research, can approximate real-time conditions without the real-life hazards to participants in field studies.

The research team chose to use a video simulation methodology for this effort. The bicycle LOS research methodology used was designed to achieve the following objectives:

- Obtain bicyclists' perceptions of the level of accommodation provided by arterial roadways using a real-time field-data collection event;
- Coincident with the field data collection event, use video simulations to obtain bicyclists' perceptions of the level of accommodation provided by arterial roadways;
- Develop an equation to correlate the video simulation responses to the real-time event responses; and
- Provide the information necessary to develop the research team's initially proposed model form.

For this NCHRP Project 3-70, a video simulation was used to collect data for the bicycle LOS model development. However, the research team took advantage of a coincident bicycle facility LOS project being conducted by FDOT's Central Office and District 7 which combined approach of field based studies with video simulation. This timely FDOT study involved a real-time event in which bicyclists rode a study course and evaluated facilities along the course. As part of this project, we filmed moving camera videos of the event route under similar conditions expected for the actual event. The videos were edited into digital sequence videos for the creation of simulation videos for video-to-field calibration.

Following the FDOT project, NCHRP Project 3-70 produced additional video for testing in a separate video simulation laboratory effort to obtain responses from additional users. To ensure the consistency of the NCHRP research video survey results, the original Ride for Science (described below) video clips were re-edited to match the format of those produced specifically for NCHRP 3-70. The NCHRP 3-70 laboratory simulation clips were shown at four locations across the United States.

Because the video simulation and its fidelity to a real-time event was an important consideration and because the NCHRP Project 3-70 team was able to take advantage of the FDOT study, the real-time event and coincident video simulation are described below.

Staff from Dowling & Associates and Sprinkle Consulting, Inc., initially developed a matrix with 30 specific combinations ("runs") of geometric and operational criteria. The matrix is provided as Exhibit 38.

The research team used the matrix as a guide to identify filming candidate locations in Tampa. Dr. Huang and Mr. Petritsch field-checked the locations to verify their geometric and operational characteristics. Some runs identified when filling out the matrix involved unlikely combinations (for example, Run #11, which specified traffic volume in outside lane > 800 vph and speed limit < 30 mph).

Consequently, some of the combinations of variable ranges were not taped for the NCHRP project 3-70 study. After discussions with Mr. Reinke, the research team selected alternative locations so that there would be locations for each value of each criterion. For example, traffic volumes of < 400, 400-800, and 800+ vph were all represented.

Theo Petritsch of Sprinkle Consulting, Inc. and Mr. Michael Munroe (a professional videographer) videotaped the bicycle locations during March and April 2006. The video platform used was a Viewpoint bicycle with Glidecam, as described above and shown in Exhibit 39.

All traffic laws were obeyed during the filming of the bicycle clips. To ensure a consistent recording methodology, and one which reflects typical bicyclists' scanning behavior, a protocol was developed, tested, and used by the researchers and videographer for proper camera panning techniques and to keep the roadway ahead in the right-center of the frame to focus on the roadway and capture driveway conditions while not focusing on objects outside the right of way.

One or two "takes" were filmed at each location. The researchers started about one city block upstream of the intersection, taped while riding at approximately 12 mph, and finished about one city block downstream of the intersection. The team also used several video clips from those filmed for the video simulation portion of the Ride for Science 2005. Those were filmed using the same procedures.

With guidance from Mr. Petritsch, Dr. Huang selected 30 bicycle clips for inclusion in the bicycle DVD. The geometric and operational characteristics of the locations depicted in these clips are shown in Exhibit 40.

Pedestrian Video Clips

Pedestrians are among the most vulnerable of travellers and are affected by a broader variety of traffic and roadway environmental factors (stimuli) than that of the motorized

Exhibit 38. Bicycle Video Clip Sampling Plan.

Run	Segment variables				Intersection variables	
	Width of outside lane (ft)	Presence / width of bike lane (ft)	Veh flow in outside lane (vph)	Speed limit (mph)	Crossing width (ft)	Control delay (s)
1	< 12	No bike lane	400 - 800	30 - 40	36 - 60	No stop
2	< 12	No bike lane	800+	< 30	60+	No stop
3	< 12	No bike lane	< 400	30 - 40	< 36	< 40
4	< 12	No bike lane	400 - 800	< 30	36 - 60	< 40
5	< 12	No bike lane	800+	40+	60+	< 40
6	< 12	≤ 4	< 400	< 30	36 - 60	40+
7	< 12	≤ 4	400 - 800	30 - 40	60+	40+
8	< 12	≤ 4	800+	40+	< 36	40+
9	< 12	≤ 4	< 400	40+	36 - 60	No stop
10	< 12	≤ 4	400 - 800	30 - 40	60+	No stop
11	< 12	≤ 4	800+	< 30	< 36	No stop
12	< 12	> 4	< 400	30 - 40	60+	< 40
13	< 12	> 4	400 - 800	< 30	< 36	< 40
14	< 12	> 4	800+	40+	36 - 60	< 40
15	< 12	> 4	400 - 800	30 - 40	< 36	40+
16	< 12	> 4	800+	40+	36 - 60	40+
17	12 +	No bike lane	400 - 800	30 - 40	36 - 60	No stop
18	12 +	No bike lane	800+	< 30	60+	No stop
19	12 +	No bike lane	< 400	30 - 40	< 36	< 40
20	12 +	No bike lane	400 - 800	< 30	36 - 60	< 40
21	12 +	No bike lane	800+	40+	60+	< 40
22	12 +	≤ 4	400 - 800	30 - 40	60+	40+
23	12 +	≤ 4	800+	40+	< 36	40+
24	12 +	≤ 4	< 400	40+	36 - 60	No stop
25	12 +	≤ 4	400 - 800	30 - 40	60+	No stop
26	12 +	≤ 4	800+	< 30	< 36	No stop
27	12 +	> 4	400 - 800	< 30	< 36	< 40
28	12 +	> 4	800+	40+	36 - 60	< 40
29	12 +	> 4	< 400	< 30	60+	40+
30	12 +	> 4	800+	40+	36 - 60	40+

modes. Previous research, model development, and nationwide deployment of non-motorized LOS mode models have demonstrated that field-based studies are the most desirable means to capture accurate perceptions of pedestrians. They place the participants in typical real-life situations and capture the participants' response to the host of stimuli present in urbanized roadway environments affecting pedestrians. However, field studies can be expensive and, depending on the range of conditions and variables being explored, represent the highest risk for participants of any method.

Exhibit 39. Bicycle Video Camera Mount.

Video simulation, however, potentially provides some significant advantages to real-time field surveys, particularly if the moving camera approach is used. The moving camera perspective gives the video simulation a greater reflection of reality than the stationary camera. Moving camera simulation also allows for a wider range of geographic participants and the testing of a greater range of variables, particularly the potentially hazardous higher truck volumes and high driveway/curb cut frequencies common in jurisdictions with minimal roadway access management practices. Finally, moving camera (video) simulation, if done based on lessons learned through recent pedestrian research, can approximate real-time conditions without the real-life hazards to participants in field studies.

Given these advantages of video simulation, the project team used video simulation to collect data for the pedestrian LOS model. Video clips were created and then shown to participants in video simulation laboratories.

Exhibit 40. Characteristics of Bicycle Video Clips.

Clip #	Start Clip	End Clip	Location	Comments	Width of outside lane	Presence/width of bike lane	Traffic volume	Speed limit	Crossing width	Control delay
1	8:00.55	8:03.05	Fowler Ave between River Hills Dr and Gillette Dr		12	9	609	50	27	No stop
2	8:01.34	8:02.04	Fowler Ave at North Dr	More traffic than Clip #3	12	9	840	50	27	No stop
3	8:16.13	8:16.43	Fowler Ave at North Dr	Less traffic than Clip #2	12	9	60	50	27	No stop
4	8:28.55	8:30.41	Collins Blvd at Alumni Dr, E side		12	3.5	136	30	65	56
5	8:32.27	8:33.34	Collins Blvd at Alumni Dr, W side		12	3.5	322	30	65	16
6	8:37.25	8:38.03	Alumni Dr at Magnolia Dr, N side	Shorter delay than Clip #7	11	4	0	30	72	0
7	9:02.46	9:04.05	Alumni Dr at Magnolia Dr, N side	Longer delay than Clip #6	11	4	46	30	72	40
8	9:04.42	9:06.00	Holly Dr at Magnolia Dr, N side		10	0	0	20	86	23
9	9:13.53	9:15.01	Holly Dr at Laurel Dr, S side		10	0	0	20	52	8
10	9:15.45	9:16.45	Fletcher Ave at Sebring Blvd, S side		11.5	0	600	40	53	No stop
11	9:20.02	9:20.45	15th St at 7th Ave, W side		12	0	0	25	33	14
12	9:21.22	9:22.43	7th Ave between 17th St and 14th St, N side		12	0	0	25	49	9
13	9:23.00	9:23.45	21st St at 7th Ave, W side		10	0	0	30	33	11
14	1:29.48	1:30.52	56th St at Busch Blvd, W side	Shorter delay than Clip #23	12	0	0	45	142	0
15	2:12.05	2:13.35	Busch Blvd at 26th St, N side		11	0	0	45	80	29
16	2:12.30	2:13.12	Busch Blvd at 26th St, N side		11	0	0	45	80	29
17	3:11.10	3:12.05	US 41 at Dover St, E side		12	0	131	55	36-60	No stop
18	3:32.30	3:33.20	US 41 at 31st St, W Side		12	0	0	55	<36	0
19	4:15.08	4:15.31	Fletcher Ave at North Palm Dr, S side		12	5	1096	45	53	0
20	4:18.00	4:18.55	Fletcher Ave at 50th St, S side		12	5	785	45	64	0
21	4:18.29	4:20.19	Fletcher Ave between 50th St and 56th St, S side		12	5	884	45	78	No stop
22	5:14.50	5:15.40	56th St at 98th Ave, W side		12	0	432	45	38	No stop
23	5:16.50	5:19.10	56th St at Busch Blvd, W side	Longer delay than Clip #14	12	0	26	45	142	80

Staff from Dowling & Associates and Sprinkle Consulting, Inc., initially developed a matrix (see Exhibit 41) with 22 specific combinations ("runs") of geometric and operational criteria to represent the typical ranges of urban arterials in metropolitan areas throughout the United States.

The research team used the matrix as a guide to identify candidate locations in Tampa and San Francisco. Herman Huang, Ph.D., of Sprinkle Consulting, Inc., field-checked the Tampa locations and Dowling & Associates staff field-checked the San Francisco locations to verify their geometric and operational characteristics. Some runs involved unlikely combinations (for example, Run #11, which specified sidewalk width < 4ft and high pedestrian volumes) and so were not included in the data collection video simulation video. After discussions with David Reinke of Dowling & Associates, the research team selected alternative locations so that there would be locations for each

Exhibit 40. (Continued).

Clip #	Start Clip	End Clip	Location	Comments	Width of outside lane	Presence/width of bike lane	Traffic volume	Speed limit	Crossing width	Control delay
24	5:23.16	5:25.46	Bullard Pkwy at 56th St		12	4	120	45	87	70
25	5:23.40	5:25.22	Bullard Pkwy at 56th St		12	4	106	45	87	70
26	6:01.46	6:02.10	S 7th St at Pasco Ave, W side		12	0	0	30	36-60	0
27	6:17.35	6:18.30	W University Ave at 10th St, S side		12	0	65	30	36-60	3
28	1:02.40	1:04.35	N Village Dr between Cypress Cir and S Village Dr, N side		12	4	63	30	36-60	No stop
29	3:30.51	3:32.27	Ehrlich Rd between Turner Rd and S Village Dr, S side		12	4	188	45	>60	50
30	3:35.55	3:37.35	N Village Dr between S Village Dr and Cypress Cir, S side		12	4	108	30	36-60	0

Note: The traffic volume is the number of vehicles in the outside lane that passed the videographer in the clip, converted to an hourly volume. In some clips few or no vehicles in the outside lane passed the videographer due to reasons such as inherently low traffic volumes or vehicles passing the videographer in the inside lane.

Exhibit 41. Pedestrian Sampling Plan.

Run	Segment variables					Intersection variables	
	Sidewalk width (ft)	Separation of walkway from traffic	Traffic speed (mph)	Traffic volume outside lane (vph)	Pedestrian volumes	Number of lanes crossed	Signal delay (sec)
1	< 4	No	30-40	400-800	Medium	2	< 30
2	4+	No	40+	800+	High	2	< 30
3	No sidewalk	No	< 30	400-800	High	2	< 30
4	4+	No	40+	< 400	Medium	2	< 30
5	No sidewalk	No	< 30	800+	Medium	4+	< 30
6	< 4	No	30-40	< 400	High	4+	< 30
7	4+	No	40+	400-800	Low	4+	< 30
8	< 4	No	40+	< 400	Medium	4+	< 30
9	4+	No	<30	400-800	High	4+	< 30
10	No sidewalk	No	30-40	800+	Medium	4+	< 30
11	< 4	No	40+	< 400	High	4+	< 30
12	4+	Yes	<30	800+	Medium	2	> 30
13	< 4	Yes	40+	800+	Low	2	> 30
14	4+	Yes	<30	< 400	Medium	2	> 30
15	< 4	Yes	<30	800+	Medium	2	> 30
16	4+	Yes	30-40	< 400	High	2	> 30
17	< 4	Yes	<30	800+	High	4+	> 30
18	4+	Yes	30-40	< 400	Low	4+	> 30
19	< 4	Yes	<30	< 400	Low	4+	> 30
20	4+	Yes	30-40	400-800	Medium	4+	> 30
21	< 4	Yes	<30	400-800	High	4+	> 30
22	4+	Yes	30-40	800+	Low	4+	> 30

value of each criterion. For example, traffic volumes of < 400, 400-800, and 800+ vph were all represented. The locations with high pedestrian volumes were mostly in San Francisco, as many parts of San Francisco are characterized by high levels of pedestrian activity. The locations with high traffic speeds and traffic volumes were mostly in Tampa, as many parts of Tampa are characterized by high speeds and volumes.

Dr. Huang and a professional videographer videotaped the pedestrian locations in Tampa and San Francisco during March and April 2006. The filming protocol followed that pioneered and tested in 2004 by Sprinkle Consulting in their research Arterial Level of Service for Arterials project for FDOT. Videotaping was performed with a steady-cam unit. A stereo microphone mounted on the camera was used during videotaping. The videographer filmed the environment while walking the intersections and facilities, obeying all pedestrian signals in the process, while Dr. Huang provided recommendations concerning filming protocol and start and end points and served as a safety coordinator (see Exhibit 42). To ensure a consistent recording methodology that reflected typical pedestrians' scanning behavior, the research team developed, tested, and used a protocol for proper camera panning techniques to keep the sidewalk on the right edge of the frame to focus as much as possible on the roadway, rather than objects outside the right-of-way.

At each location, the researchers filmed multiple "takes," each with a different length of signal delay. The researchers started about 100 yards upstream of the intersection, taped while walking at a normal (approximately 4 ft/sec) pedestrian speed, and finished about 100 yards downstream of the intersection.

Exhibit 42. Pedestrian Video Camera Mount.

Dr. Huang selected 32 of the video pedestrian clips for inclusion in the DVD that would be used during the pedestrian roadway LOS data collection events. Exhibit 43 lists the geometric and operational characteristics of the locations shown in these clips.

Development of Master DVDs

The research team members decided in the spring of 2006 that a maximum of 10 video clips for each mode were to be viewed in each study location and ratings gathered for each from participants. The decision to limit the videos to 10 clips per mode was partially based on the need to maintain the attention of study participants and also to maintain a total testing time of between 2 and 3 hours, including time for an informal focus group. The team also decided to select four specific clips for each mode to be shown in each of the four cities, so that one could later attempt to isolate the influence of variables such as population density, population, and expectation of travel conditions on traveler ratings of LOS across the four cities. Next, six additional clips per mode were selected to be shown in each of the four study locations. Finally, a pilot test clip for each mode was selected and shown in each of the fours cities to help orient participants to the mode they were to rate for that portion of the study.

Exhibit 44, Exhibit 45, and Exhibit 46 show the specific sequence of video clips shown in each of the four study locations. Clips shown in all four locations are highlighted—they show up at different points in the sequence. The specific sequence of clips shown in each city was intentionally randomized so as to minimize the likelihood of respondent fatigue biasing the results. Efforts were made to normalize the length of testing time in each of the four study locations while providing a range of factors to participants in each study location.

Using the GMU Media Laboratory facilities and staff, a set of master DVDs was created for each of the four testing locations. Efforts were made to maintain the highest possible quality of video to enhance the video presentation portion of the study; this requirement resulted in the creation of one DVD per mode per city, resulting in 12 master DVDs, which were later used in the data collection process.

To maintain consistency among the clips, GMU Media Laboratory staff worked with the video production crew hired by Sprinkle Consulting to ensure that video clips had the same look and feel of those created by GMU. GMU Media Laboratory staff provided detailed editing instructions, which were followed perfectly by the production crew in Florida, while creating the pedestrian and bicycle clips. Each video clip was edited to include an opening title which read "Clip XXX" on a black background, next the title would fade out and the video clip showing a particular trip would begin. At

Exhibit 43. Geometric & Operational Characteristics of Pedestrian Video Clip Locations.

Clip #	Start Clip	End Clip	Location	Direction	Comments	Sidewalk width	Separation	Traffic speed	Traffic volume	Ped volume	Number of lanes	Signal Delay
201	10:01.10	10:02.53	Holly Dr at Magnolia Dr, N side	WB, with traffic		No sidewalk	No	20	175	Low	4	36
202	10:01.37	10:02.35	Holly Dr at Magnolia Dr, N side	WB, with traffic		No sidewalk	No	20	248	Low	4	36
203	10:28.51	10:30.08	Collins Blvd at Alumni Dr, E side	NB, with traffic	Shorter delay	10	Yes	30	234	Medium	4	14
204	10:31.27	10:33.37	Collins Blvd at Alumni Dr, E side	NB, with traffic	Longer delay	10	Yes	30	83	Medium	4	65
205	11:04.40	11:05.50	Alumni Dr at Magnolia Dr, N side	WB, with traffic		10	Yes	30	206	Low	4	0
206	12:03.45	12:06.30	Fowler Ave at 56th St, S side	EB, with traffic		5	Yes	50	567	Low	9	78
207	12:04.13	12:06.12	Fowler Ave at 56th St, S side	EB, with traffic		5	Yes	50	605	Low	9	78
208	12:20.15	12:22.10	Fletcher Av at Bruce B Downs Blvd, S side	WB, against traffic	Longer delay	No sidewalk	No	45	939	Low	8	40
209	12:23.10	12:24.30	Fletcher Av at Bruce B Downs Blvd, S side	WB, against traffic	Shorter delay	No sidewalk	No	45	514	Low	8	9
210	12:35.15	12:36.40	Magnolia Dr at Holly Dr, W side	SB, with traffic		No sidewalk	No	30	212	Medium	4	23
211	13:03.20	13:04.20	Bearss Ave at North Blvd, N side	WB, with traffic		4	Yes	45	660	Low	3	0
212	13:22.00	13:24.10	Dale Mabry Hwy at Ehrlich Rd, W side	SB, with traffic		5	Yes	45	388	Low	7	47
213	13:33.01	13:35.56	Dale Mabry Hwy at Tampa Bay Blvd, E side	SB, against traffic	Longer delay	9.5	Yes	45	638	Low	7	98

(continued on next pg)

Exhibit 43. (Continued).

Clip #	Start Clip	End Clip	Location	Direction	Comments	Sidewalk width	Separation	Traffic speed	Traffic volume	Ped volume	Number of lanes	Signal Delay
214	14:05.23	14:07.53	Dale Mabry Hwy at Tampa Bay Blvd, E side	SB, against traffic	Shorter delay	9.5	Yes	45	792	Low	7	55
215	14:13.50	14:15.30	7th Ave at 15th St, N side	WB, with traffic		8	Yes	25	180	Medium	2	35
216	14:21.44	14:22.44	21st St at 7th Ave, W side	SB, with traffic		6	No	30	360	Medium	2	0
217	14:24.02	14:25.42	21st St at 7th Ave, W side	SB, with traffic		6	No	30	72	Medium	2	32
218	15:02.35	15:04.05	Market St at Kearney St, N side	EB, against traffic		15-18	Some separation (bus bays, stops, meters)	<30	80	High	4-PM peak; 2 otherwise	22
219	15:31.10	15:33.04	Stockton St at Clay St, E side	NB, with traffic	Longer delay	6-10	Yes	<30	126	High	3-PM peak; 2 otherwise	43
220	15:38.41	15:39.49	Stockton St at Clay St, E side	NB, with traffic	Shorter delay	6-10	Yes	<30	0	High	3-PM peak; 2 otherwise	0
221	16:06.10	16:07.40	Stockton St at Washington St, E side	NB, with traffic		4 at narrowest	Yes	<30	0	High	2	0
222	16:22.11	16:24.15	Stockton St at Broadway St, E side	NB, with traffic	Longer delay	6	Yes	<30	116	High	5-AM peak; 6-PM peak; 4 otherwise	54
223	16:36.01	16:37.17	Stockton St at Broadway St, E side	NB, with traffic	Shorter delay	6	Yes	<30	0	High	5-AM peak; 6-PM peak; 4 otherwise	0
224	17:18.30	17:19.55	Grant Ave at Jackson St, E side	SB, against traffic		4 at narrowest	Yes	<30	85	High	2	29

Exhibit 43. (Continued).

Clip #	Start Clip	End Clip	Location	Direction	Comments	Sidewalk width	Separation	Traffic speed	Traffic volume	Ped volume	Number of lanes	Signal Delay
225	17:23.17	17:24.45	Geary Blvd at Divisadero St, S side	EB with traffic	Shorter delay	8-10	Yes	40+	205	Medium	4	18
226	17:25.51	17:27.38	Geary Blvd at Divisadero St, S side	EB with traffic	Longer delay	8-10	Yes	40+	303	Medium	4	39
227	18:20.35	18:21.40	Grant Ave at California St, E side	SB, against traffic		6	Yes	<30	277	High	5-AM peak; 6-PM peak; 4 otherwise	0
228	18:30.31	18:32.30	Post St at Stockton St, S side	WB, against traffic		6+	Yes	Unknown	121	Low	3	43
229	19:00.57	19:03.00	Post St at Stockton St, S side	EB, with traffic		6+	No	Unknown	88	Low	3	40
230	20:25.35	20:27.00	3rd St at Mission St, E side	NB, with traffic		6+	Yes	Unknown	0	High	4+	20
231	2:19.00	2:21.55	Dale Mabry Hwy, between State St and Carmen St, W side	SB, with traffic		5	Yes	35	370	Low	2	0
232	2:11.25	2:14.40	Hillsborough Ave, between Armenia Ave and Tampania Ave, N side	WB, with traffic		6+	No	45	880	Low	2	0

Note: The traffic volume is the number of vehicles that passed the videographer in the clip, converted to an hourly volume.
In some clips few or no vehicles passed the videographer due to reasons such as inherently low traffic volumes or vehicles queued at a light.

Exhibit 44. Pedestrian Clip Sequence at Testing Locations.

Presentation Order	Location of Video Laboratory – Pedestrian Clips Shown			
	New Haven, CT	Chicago, IL	Oakland, CA	College Station, TX
Pilot Clip	212	212	212	212
1	223	201	215	208
2	208	226	220	217
3	226	225	206	215
4	204	208	201	214
5	205	219	227	201
6	203	228	226	230
7	201	211	209	218
8	231	215	216	232
9	215	229	224	226
10	210	222	208	221
Total Clip Time	16.2 min	18 min	16 min	19.4 min

Note: Table shows the sequence of clips shown in each city. Entries are the clip identification numbers. Shaded clips were shown in all four cities. Sequence of clips shown was intentionally randomized in each city to counteract fatigue effects.

the conclusion of each video clip, GMU Media Laboratory staff looped the DVD back to a consistent title page which included a complete list of the video clips on each of the DVDs. This allowed the operator to then click the mouse on the next appropriate clip when participants were ready to begin rating the next video clip. Using the information provided in Tables 3-3 through 3-5, one DVD per mode per city was generated, resulting in 12 unique DVDs. These DVDs were then labeled by the GMU Media Laboratory staff to ensure ease of selection by the facilitator of each laboratory session.

4.4 Video Lab Protocol

Selection of Video Lab Cities

Four metropolitan areas were selected for the Phase 2 auto, bike, and pedestrian video labs. They were Chicago, Illinois; San Francisco, California; New Haven, Connecticut; and College Station, Texas. They were selected to obtain a range of population and climates of the United States based on the hypothesis to be tested that the population of the urban area and the climatic area of the US might influence the degree of satisfaction reported by subjects in the video laboratories.

There are 922 urban areas in the United States with a population of at least 10,000 (U.S. Census [**94**]). These urban areas are ranked by population and then stratified into four groups, each group representing approximately one-quarter of the urban area population in the United States. The results are as shown in Exhibit 47.

The eight largest metropolitan areas of the United States (i.e., New York, Los Angeles, Chicago, Philadelphia, Dallas, Miami, Washington DC, and Houston) hold one-quarter of the urban area population of the United States. Chicago was selected to represent these largest metropolitan areas of the United States.

Exhibit 45. Bicycle Clip Sequence at Testing Locations.

Presentation Order	Location of Video Laboratory – Bicycle Video Clips Shown			
	New Haven, CT	Chicago, IL	Oakland, CA	College Station, TX
Pilot Clip	326	326	326	326
1	301	319	302	311
2	323	308	310	328
3	321	306	305	324
4	320	309	324	315
5	317	320	327	309
6	312	318	321	313
7	309	304	309	303
8	307	324	322	319
9	314	321	330	320
10	324	329	320	321
Total Clip Time	13 min	13 min	13 min	13 min

Note: Table shows the sequence of clips shown in each city. Entries are the clip identification numbers. Shaded clips were shown in all four cities. Sequence of clips shown was intentionally randomized in each city to counteract fatigue effects.

Exhibit 46. Automobile Clip Sequencing at Testing Locations.

Presentation Order	Location of Video Laboratory – Auto Clips Shown			
	New Haven, CT	Chicago, IL	Oakland, CA	College Station, TX
Pilot Clip	25	25	25	25
1	21	20	12	15
2	55	56	56	7
3	52	10	8	52
4	60	51	65	13
5	53	14	59	58
6	56	2	29	56
7	54	62	6	2
8	2	63	15	1
9	15	52	2	61
10	57	15	52	64
Total Clip Time				

Note: Table shows the sequence of clips shown in each city. Entries are the clip identification numbers. Shaded clips were shown in all four cities. Sequence of clips shown was intentionally randomized in each city to counteract fatigue effects.

The next-largest metropolitan areas hold another quarter of the urban area population in the United States: Detroit, Boston, Atlanta, San Francisco, Riverside, Phoenix, Seattle, Minneapolis, San Diego, St Louis, Baltimore, Pittsburgh, Tampa, Denver, Cleveland, Cincinnati, Portland, Kansas City, Sacramento, San Jose, San Antonio, Orlando, Columbus, Providence, Virginia Beach. San Francisco was selected to represent this group of large metropolitan areas.

The other 800+ metropolitan areas constituting the remaining 50% of the U.S. urban area population are too numerous to conveniently list here. The research team selected from the Census list of these cities the following two metropolitan areas to represent the lesser populated metropolitan areas of the United States: New Haven, Connecticut (population between 300,000 and 1.5 million), and College Station, Texas (population under 300,000).

Thus, the four metropolitan areas for the Phase 2 auto, bike, and pedestrian video labs were Chicago, Illinois; San Francisco, California; New Haven, Connecticut; and College Station, Texas.

IRB Review

Most research institutions require, when working with human or animal subjects, that the study undergo a review by an independent review board to ensure that no undue harm will occur to study participants. George Mason University has its own Internal Review Board (IRB) to oversee research studies within the University. The effort to obtain approval to proceed with the study included

- Completing the IRB application for approval of study
- Providing the IRB with an overview of the study protocol
- Providing the IRB with sample survey instruments and testing material

Researchers for this study received approval from the GMU IRB in June of 2006 to proceed with the study as described. Appendix B includes the materials submitted to the IRB including Study Protocol and the Application for Human Subjects Research Review.

Recruitment

Based on input from the team and ultimately the project's Principal Investigator, a decision was made that the minimum number of participants in each location was 30 and a maximum of 35 participants was budgeted for each study location. Phase I study results revealed that, although age influenced participant ratings—which is consistent with studies con-

Exhibit 47. Stratification of MSAs Into Equal Population Groups.

Group	Population Range	Number of SMSAs	Total Population	Percentage of U.S. Population
1	Pop.> 5M	8	65,154,790	24.9
2	1.5M < Pop < 5M	25	64,389,536	24.6
3	300K < Pop < 1.5M	104	66,586,646	25.5
4	13K < Pop < 300K	785	65,404,019	25.0
Total		922	261,534,991	100.0%

MSA = Metropolitan Statistical Area, as defined by U.S. Census ducted by Sprinkle Consulting, gender was not found to be a statistically significant contributor to participant ratings. Based on these findings, the study team determined that recruiting of participants should be based on the following criteria in order of importance:

- Age (seek equal distribution between young, middle, and older aged participants)
- Gender (equal distribution between males and females)
- Regular users of modes other than private vehicle, in particular bicyclists

Dr. Flannery of GMU recruited subjects in each location by establishing contact through the following:

- Community senior citizen centers
- Bicycle clubs
- Community/neighborhood associations

To assist in recruiting, posters and flyers, developed for each location, included all relevant information for the study (e.g., location, time, date, and participant requirements). These posters and flyers were sent to the contacts established through the various organizations. Posters also included tear-off contact information to register for the study. Appendix C contains an example flyer used in the Chicago location.

Exhibit 48 breaks down the participants by age and gender in each of the four study locations.

From the demographic survey, information was extracted on the regularity of participants to use modes other than private automobile in their travel. Researchers sought to include participants who regularly take non-recreational bike and pedestrian trips, as well as, regular transit users.

Exhibits 49 through 51 show a breakdown of participant mode use by study location. Chicago had the highest percentage of daily walkers among the cities surveyed. Oakland had the highest percentage of daily bicycle riders. College

Exhibit 48. Characteristics of Participants.

Age Group (years of age)	New Haven, CT		Chicago, IL		San Francisco, CA		College Station, TX		Total
	Male	Female	Male	Female	Male	Female	Male	Female	
Young (18-35)	2	4	4	4	6	12	3	5	40
Middle (36-50)	9	8	9	6	9	8	8	6	63
Older (60+)	2	9	6	6	1	2	6	10	42
Total	13	21	19	16	16	22	17	21	145

Exhibit 49. Non-Recreational Pedestrian Travel By Participants (More than Two Blocks).

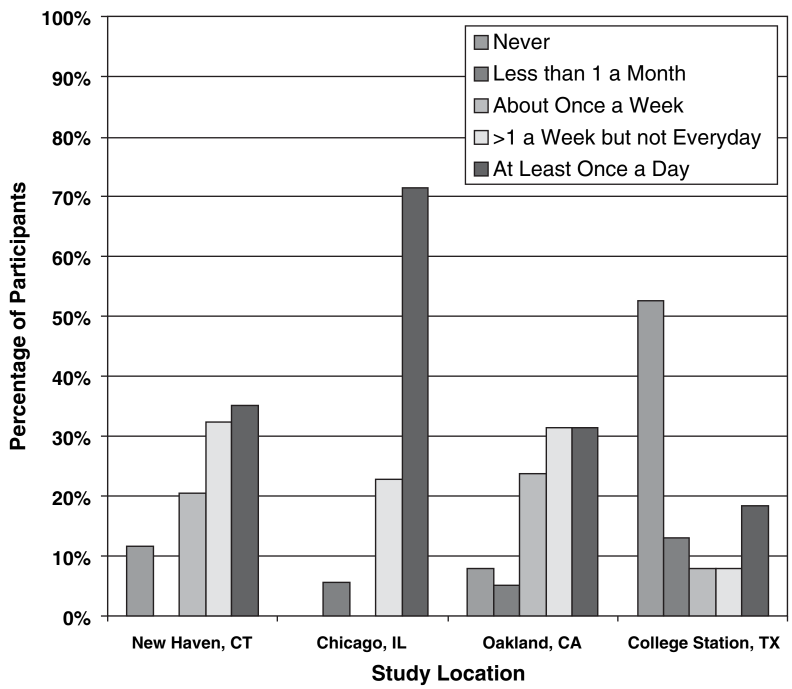


Exhibit 50. Non-Recreational Bicycle Usage By Participants.

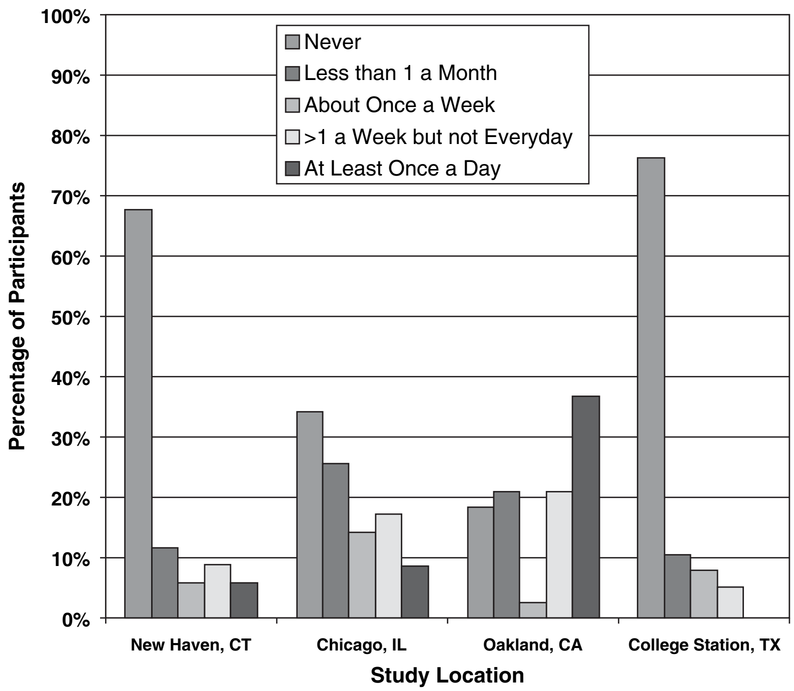


Exhibit 51. Transit Usage By Study Participants.

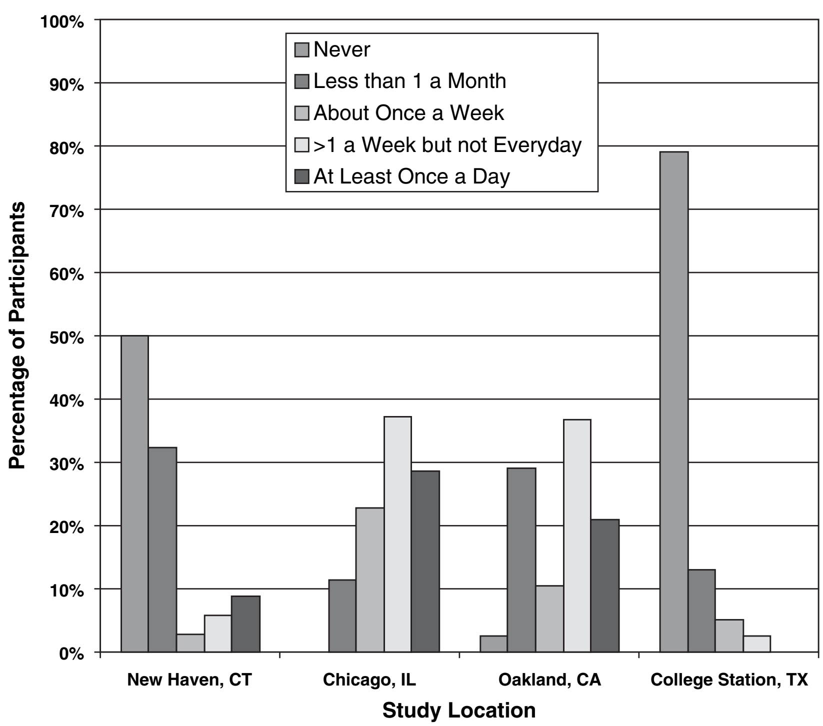


Exhibit 52. Comparisons of Socioeconomic Characteristics of Sample with National Averages.

Group	National Average	Sample	Bias in results?
Male	49%	45%	No, video lab participants mirror national average.
Age over 60	16%	29%	The video lab oversampled people over 60, which might possibly have a slight positive effect on LOS ratings for the bicycle video clips.
Single-family detached dwelling unit	60%	36%	The video lab undersampled people living in single-family homes, which might possibly have a slight positive effect on LOS ratings for the pedestrian video clips.
Has vehicle available	90%	91%	No, video lab participants mirror national average.

Source for national averages: US Census, 2000, American Fact Finder, Tables P8, H32, and H44.

Station had the highest percentage of participants who never walked, never biked, and never rode transit.

Validity of Video Lab Respondent Sample

The selected demographic characteristics of the video lab participants were compared with national averages (presented in Exhibit 52). With the exception of seniors (who were oversampled) and single-family home residents (who were undersampled), the video labs generally secured a representative national average of participants.

Survey Instrument

Survey instruments were developed to standardize data collection of input from the study participants. Study participants were asked to rate 10 video clips per mode on a six-point scale (A-F). Study participants were instructed that the A to F scale was similar to that used in grade school in which A was to represent the highest performance and F to represent the worst performance.

Pilot tests conducted by GMU in Phase I of NCHRP 3-70 revealed that trip purpose (i.e.,leisure versus time-constrained trips) influenced participant ratings of service quality; as a result, the team decided to focus study participants on time-constrained trips to better align with procedures in the HCM which are typically focused on peak-hour conditions. Study participants were instructed to choose the rating that best represented their assessment of quality as a commuter after watching each video clip.

A demographic survey instrument was also developed by team members for use in data analysis to better understand the motivation for responses by groups or individual participants. The survey contains questions about participant age group, gender, typical travel mode, and the use of all modes (including transit) during a typical day, week, and month. The survey instruments were developed to be easily understood and easily completed by the participants. Appendix A includes the survey instruments created for the study.

Pilot Tests

Pilot test sessions, using 14 GMU graduate students, were held to test the study methodology, to ensure that the surveys were easily understood by the participants, to refine our presentation of the materials, and to refine the study materials (such as how many clips to show and needing to increase font size for older drivers). Pilot test session data will not be included in the final database, but is available for review in hard copy format.

One of the primary goals of the pilot test sessions was to determine if the order of video presentation by mode influenced ratings. For example, should the videos be shown in the order Auto Driver, Bicycle Rider, Pedestrian or in the order Pedestrian, Bicycle Rider, Auto Driver? To control for the order, one order was presented to one study group and the other order was presented to the second study group. It was determined that order of presentation had a slight influence on participant ratings, in particular for the auto video clips. Using this information, the team determined that the videos needed to be shown in a consistent order at each of the four locations to control for potential mode order bias in participant ratings. The pilot sessions also revealed that the study materials were understandable to the participants, but that the font needed to be increased in some cases to account for vision loss in older participants. In addition, some of the questions in the demographic survey were rearranged to provide better consistency in terms of those questions that required filling in a blank versus circling a response.

Video Lab Sessions

Laboratory sessions were held in four locations, as previously noted. The study locations selected (large hotels in each of the four cities) had access to transit facilities, as well as, available parking; this provided the participants with easy to reach locations as well as a sense of security. Two study sessions were held in each location to enable older participants to attend daytime sessions (to address their desired times of arrival) and to enable working professionals to attend evening sessions. In each location, the daytime session was held from 10am-12:30pm and the evening session was held from 6:00-8:30pm.

Hotel meeting rooms were set up classroom style with two participants seated at each roughly 10-ft-long table. There was an aisle between two rows of tables in which the video equipment was placed, and a large-screen projector screen was set up at the front of the room. Light refreshments were provided during each session.

As participants arrived, they were given a unique identifier code which was written on their survey sheets for them and also corresponded to the receipt sheets generated for each location. The unique identifier scheme is required by GMU to keep the participants' information confidential while allowing the researchers to later make correlations between responses and some other demographic (i.e., age or sex). The participants were then asked to complete a demographic questionnaire while waiting for the remaining participants to arrive. Once all participants had arrived, Dr. Flannery thanked them all for attending and gave a short introduction to help them understand the task at hand. The opening remarks explained the study's purpose, who the study sponsor was, general procedures, location of facilities, explanation of the forms (survey forms, Informed Consent Form), their rights as study participants, and the schedule of the study. The clips were shown in the order of pedestrian mode, bicycle mode, and finally auto mode. Participants were asked to keep their opinions to themselves during the study so as to not influence their neighbors and were informed that, at the end of the clips, a short focus group would be conducted in which they could provide more details on their opinions.

A practice clip was shown to participants at the beginning of each mode to familiarize them with the task at hand. Questions were clarified, if needed, once participants had completed rating the practice clip. The participants were not informed what specifically to rate each clip on—only that they should rate the clip on how satisfied as a traveler. Upon completion of each mode, typically 20 to 25 minutes after the session had started, the participants had a 10- to 15-minute break before beginning the next mode video session. After all video clips had been rated by the participants, a short break was taken to set up for the focus group session. During the focus group session, participants were asked to discuss what factors greatly influenced their ratings in each of the mode video sessions. These comments were noted by Dr. Flannery on her laptop, and efforts were made to focus the participants on one mode at a time and to complete discussion of that mode before moving to the next.

At the end of the session, the participants were allowed to ask questions and then were compensated for their time with a $75.00 honorarium paid in cash and required to sign a receipt. Then forms were collected, and participants were thanked for their contribution to the study.

4.5 Effects of Demographics on LOS

This section presents the results of an investigation into the effects of various socioeconomic and location factors on clip ratings for auto, bicycle, and pedestrian modes. The effects of metropolitan area location on transit LOS ratings could not be tested because of differences in the transit services provided in each metropolitan area.

For each of the auto, bicycle, and pedestrian modes, four common film clips were shown in each of the four metropolitan regions. We used the ratings on these clips to test for effects of socioeconomic and location factors.

For each factor, we divided the respondents into a test group and a control group. The test group contained those respondents for which the factor was present (e.g., persons having one or more cars available); the control group contained those respondents for which the factor was not present (e.g., persons not having a car available).

Once the groups were defined, we used a nonparametric randomization (bootstrap) (see Davison and Hinkley [**95**]) test to determine whether the difference in mean ratings for an individual clip was significant. The sample size is denoted by N and the size of the control group is denoted by k. For hypothesis testing, the bootstrap method works as follows:

1. Compute the difference in means between the test group and the control group.
2. Generate a random permutation of cases. For each permutation, compute the mean for the first k cases and the last $N - k$ cases. If the difference is greater than or equal to the difference computed in Step 1, add 1 to an indicator variable X. Repeat this step B times.
3. Divide X by $B - 1$. The result is the estimated probability that the difference computed in Step 1 results from chance alone.

The bootstrap method has significant advantages over traditional hypothesis testing, mainly because it is nonparametric and, therefore, makes no assumptions about the shape of the distribution of responses.

For this analysis, we defined significance to be at the 10% level (i.e., the probability that the difference in ratings could have arisen by chance alone is less than 10%.). We judged the bootstrap test to be superior to other tests that might be used for the following reasons:

- Standard analysis of variance requires that cell sizes be equal, or nearly so (see Searle [**96**]). This assumption is violated for all the tests considered.
- Classic hypothesis tests (e.g., the t-test) assume that responses are normally distributed.

For each clip, we defined an indicator variable *y* as follows:

- $y = +1$ if the mean rating for the test group is *higher* than the mean rating for the control group, and the difference is significant.
- $y = -1$ if the mean rating for the test group is *lower* than the mean rating for the control group, and the difference is significant.
- $y = 0$ if the mean rating for the test group is not significantly different from the mean rating for the control group.

The scores for each of the four control clips for a given mode were added to form a *cumulative score* for the individual factor for that mode. Given that there were four common clips for each mode, the score for each factor for a given mode could range from –4 to +4. A factor was deemed to be *significant* if the score for that mode was –3 or +3; this meant that for three of the four common clips for that mode, the differences in ratings between the test and control groups were significant and in the same direction. A factor was deemed to be *highly significant* if the score for that mode was –4 or +4; this meant that for all four common clips for that mode, the differences in ratings between the test and control groups were significant and in the same direction.

The tested socioeconomic factors are listed in Exhibit 53.

Effects of Demographics on Auto LOS Ratings

Significant differences in auto clip ratings are shown in Exhibit 54. Although there were several significant differences (three of the four clips consistently rated higher or lower), none was highly significant.

Exhibit 53. Test and Control Groups for Socioeconomic and Location Factors.

Test group	Control group
Metro area is New Haven	Metro area is Chicago
	Metro area is San Francisco Bay Area
	Metro area is College Station
	All other regions
Metro area is Chicago	Metro area is San Francisco Bay Area
	Metro area is College Station
	All other regions
Metro area is San Francisco Bay Area	Metro area is College Station
	All other regions
Metro area is College Station	All other regions
Metro area population ≥ 1 million	All other respondents
Age is 18 - 35	All other respondents
Age is 36 - 60	All other respondents
Age is 60+	All other respondents
Sex is male	All other respondents
Has a vehicle available	All other respondents
Has a bike available	All other respondents
Respondent is employed	All other respondents
Dwelling unit is single-family home	All other respondents
Respondent owns the home	All other respondents
Walks non-recreational > 2 blocks more than once a week	All other respondents
Cycles non-recreational > 2 blocks more than once a week	All other respondents
Uses transit more than once a week	All other respondents
Commutes by auto (drive alone or shared ride)	All other respondents
Commutes by transit	All other respondents

Exhibit 54. Significant Differences in Ratings—Auto.

Group		Group Sample Size		Mean Rating Difference[a]
Test	Control	Test	Control	
Highly Significant Differences				
None				
Significant Differences				
Metro area is New Haven	Metro area is College Station	34	38	-1.02
Metro area is New Haven	All other respondents	34	111	-0.85
Metro area is New Haven	Metro area is Chicago	34	35	-0.84
Has a vehicle available	All other respondents	132	13	0.67
Region is College Station	All other respondents	38	107	0.50

[a] Mean of test group rating minus control group rating

The following are the main findings for auto:

- Respondents in the New Haven metro area consistently rated the clips lower than did respondents from other metropolitan areas.
- Respondents with a vehicle available tended to rate the clips higher than did respondents from other metropolitan areas.
- Respondents from the College Station metro area tended to rate the clips slightly higher than did other respondents.

However, none of these differences were found to be "highly significant," thus all data from all metropolitan areas and demographic groups were pooled for auto LOS model development.

Effects of Demographics on Bicycle LOS Ratings

Significant differences in bicycle clip ratings are shown in Exhibit 55. The following factors resulted in highly significant differences in the LOS ratings:

- Respondents from the New Haven metro area consistently rated the clips lower than did respondents from the other metropolitan areas.
- Male respondents tended to rate the clips slightly higher than did female respondents.
- Respondents from metro areas with a population of over 1 million (Chicago and San Francisco Bay Area) tended to rate the clips slightly higher than did respondents from the other two metro areas.

The following factor was found to be significant:

- Respondents aged over 60 tended to rate the clips slightly higher than did other respondents.

For these reasons "metropolitan area" was included as an explanatory variable for the bicycle LOS model development. However, analysts would not generally have information on the sexual split between bicyclists, so sex was excluded from the bicycle LOS model development.

Effects of Demographics on Pedestrian LOS Ratings

Significant differences in pedestrian clip ratings are shown in Exhibit 56. The following factors resulted in highly significant differences in the pedestrian LOS ratings:

- Respondents who walk more than two blocks for non-recreational purposes more than once a week tended to rate the clips lower than did other respondents.

The following factors resulted in significant differences in the LOS ratings:

- Respondents from the College Station metro area tended to rate the clips higher than did other respondents.
- Respondents from the Chicago metro area tended to rate the clips lower than did respondents from the College Station metro area.
- Respondents who have a bicycle available tended to rate the clips slightly lower than did other respondents.
- Respondents who live in single-family detached dwelling units tended to rate the clips slightly higher than did other respondents.

Only the extent of non-recreational walking was a highly significant factor affecting pedestrian LOS ratings. However, this a demographic variable unlikely to be known by analysts using the pedestrian LOS method. Consequently, this variable was excluded from the pedestrian LOS model.

Exhibit 55. Significant Differences in Ratings—Bicycle.

Group		Group Sample Size		Mean Rating Difference[a]
Test	Control	Test	Control	
Highly significant differences				
Metro area is New Haven	Metro area is San Francisco Bay Area	34	38	-0.87
Metro area is New Haven	All other respondents	34	109	-0.75
Metro area is New Haven	Metro area is College Station	34	36	-0.71
Metro area is New Haven	Metro area is Chicago	34	35	-0.68
Male	All other respondents	65	78	0.47
Metro area population ≥ 1 million	All other respondents	73	70	0.40
Significant differences				
Age is 60+	All other respondents	42	101	0.61

[a] Mean of test group rating minus control group rating

Exhibit 56. Significant Differences in Ratings – Pedestrian.

Group		Group sample size		Mean rating difference[a]
Test	Control	Test	Control	
Highly significant differences				
Walks non-recreational > 2 blocks more than once a week	All other respondents	97	48	-0.60
Significant differences				
Metro area is College Station	All other respondents	38	107	0.78
Metro area is Chicago	Metro area is College Station	35	38	-0.77
Has a bike available	All other respondents	107	38	-0.76
Dwelling unit is single-family home	All other respondents	52	93	0.36

[a] Mean of test group rating minus control group rating

The metropolitan area showed up as a significant factor affecting pedestrian LOS ratings for a couple of metropolitan areas, so this factor was included in the pedestrian LOS model development.

4.6 Transit On-Board Surveys

The transit survey methodology used for this project was designed to achieve the following objectives:

- Confirm the quality of service factors important to passengers who have already decided to make a trip by transit;
- Ask questions in a form relevant to passengers (relating to their trip), but provide results in a form relevant to the project (relating to a specific urban street facility);
- Maximize the amount of useful information that could be gleaned from a limited number of survey locations; and
- Provide the information necessary to develop the project team's initially proposed transit model form, while also providing data that could be used to develop alternative model forms, if necessary.

Agency Coordination

Five transit agencies were contacted to obtain permission to conduct surveys: TriMet in Portland, Oregon; Washington Metropolitan Area Transit Authority (WMATA) for Northern Virginia; Broward County Transit (BCT) for the Fort Lauderdale, Florida area; the San Francisco Municipal Railway (MUNI) (which operates bus and rail services within the City of San Francisco); and AC Transit (which operates express and local bus services in and between several cities in the San Francisco metropolitan area). These agencies were chosen for geographic variety, a range of service and demand conditions, and their proximity to research staff offices. All of the agencies were provided with an explanation of the purpose and expected outcomes of the NCHRP 3-70 project, a draft copy of the survey form, and the route(s) desired to be surveyed. All readily agreed to participate.

Under TriMet's union contract, drivers of buses on which surveys will occur must be notified in advance, which required that specific trips to be surveyed had to be identified well in advance. This requirement did not exist at the other agencies; however, the drivers there were also given advance notice, so that they would be aware that the surveys would be occurring. Surveyors at all sites carried a letter from the transit agency authorizing them to be on the bus, in case a driver had any questions. WMATA also required that the names of the surveyors be provided in advance so that they could be listed on the letter.

Field Data Collection

The following roadway-related information was collected along the entire route:

- Average stop spacing (bus stops/mile);
- Stop-specific data:
  - Presence of shelter (yes/no);
  - Presence of bench (yes/no) [including a bench inside a shelter];
  - Presence of sidewalk or path (yes/no);
  - Presence of ditch or other obstacle between sidewalk and street (yes/no);
  - Bus stop waiting area separation from auto traffic (curb-tight, sidewalk set back from street, on median or traffic island, off-street);
  - Street width (lanes);
  - Median type (raised/painted/none);
  - Traffic control at stop (signal/all-way stop/bus street stops/side street stops/roundabout/mid-block location/off-street location); and
  - Crosswalk type at stop (marked/unmarked/no legal crosswalk).

The following transit-related information was collected:

- Stop location for each stop on the surveyed routes;
- Survey route frequency—peak and midday (bus/h);

- Effective frequency on arterial—peak and midday (bus/h);
- Survey route service span (h/day);
- Effective service span on arterial (h/day);
- Scheduled bus arrival/departure times;
- Number of seats on the bus; and
- Available standee area on bus.

"Effective frequency" and "effective span" included all routes along a portion of the urban street serving the same destination as the surveyed route. For example, if the survey route operated two trips per hour during the peak hour, and another route on the same street serving the same destination also operated two trips per hour during the peak hour, the effective peak-hour frequency was four trips per hour.

Survey Form Development

An initial draft of the survey form was described in the Phase 1 "Transit Data Collection Plan" memo and subsequently approved by the project panel. In working with TriMet to obtain permission to conduct surveys on their buses, TriMet's Marketing Information Department offered to review and comment on the survey form, based on their experience conducting on-board surveys. Their review resulted in wording changes to some of the questions to shorten the descriptions, while keeping the original meaning. A Spanish version of the pilot survey was also developed.

The revised survey form and the survey procedures were pilot tested on April 22, 2004, on TriMet Line 15. Based on user feedback, the final question on the pilot survey, which asked persons to rank the quality of service factors most important to them, was substantially changed to reduce confusion. In addition, the number of factors presented on the final version of the survey was reduced from 29 to 17 by eliminating factors that received few to no responses among users' five most important factors. Spanish and large-print (22-point font) versions of the final survey were also developed.

TriMet requested that the survey form used on their buses resemble an official TriMet survey, so the TriMet logo, a TriMet-tailored explanation of the survey purpose, and a TriMet information phone number were included on the TriMet survey form. The other agencies wanted the surveys distributed on their buses to *not* resemble official agency surveys, so a generic survey purpose description resembling the one shown on the initial survey draft was used for those agencies.

The final version of the Phase 1 survey forms are given in Exhibit 57, reduced in size from legal-size paper. Each survey was given a unique four-digit serial number, with the first digit indicating the route it was used on:

- Portland: Line 15 (pilot test)
- Portland: Line 14
- Portland: Line 44
- Northern Virginia: Line 38B
- Northern Virginia: Line 2B
- Broward County: Line 18

The questions asked on the Phase 1 survey were as follows:

1. The stop where the person would get off the bus. (Surveyors recorded the stop where each passenger boarded and received a survey, using the survey's serial number, eliminating the need to ask persons where they boarded.)
2. The number of times a week the person rode the bus.
3. The major reason why the person chose to ride the bus (had a car but preferred the bus, chose not to own a car because bus service was available, did not own a car, didn't drive or know how to drive).
4. The person's satisfaction with their trip *today* on the bus, using a 1 (very dissatisfied) to 6 (very satisfied) scale:
   a. Getting to the bus stop
   b. Waiting for the bus
   c. Riding on the bus
   d. The overall trip
5. The person's satisfaction *in general* with the following aspects of the bus route, using the same 1-to-6 scale:
   a. Close to home
   b. Close to destination
   c. Sidewalk connects to stop
   d. Crossing street to stop is easy
   e. Shelter is provided
   f. Bench is provided
   g. Frequency of buses
   h. Times of day the route operates
   i. Reliability of service
   j. Seat available
   k. Wait time for bus
   l. Not overcrowded
   m. Friendly drivers
   n. Amount of time to reach destination
   o. Seat comfort
   p. Smooth ride
   q. Temperature inside bus is comfortable
6. Finally, persons were asked to rank up to five factors from the above list that were the most important to them.

In Phase 2, the length of the survey was substantially reduced by eliminating questions 5 and 6. As described in Section 3 of this working paper, the Phase 1 responses to these questions confirmed the importance of the quality-of-service factors given in the TCQSM, and it was not thought necessary to continue to ask these questions. In addition, one objective of the Phase 2 surveys was to sample more crowded routes than were sampled in Phase 1, and it was thought that a shorter survey

Exhibit 57. Phase 1 Transit Survey Form.

TRIMET 2«Serial

Please take a few minutes to fill out this TriMet survey.
The purpose of the survey is ask your satisfaction level with bus service on this route.
When finished, please place the survey in the envelope near the door.
Thank you for riding TriMet.

1. First, where will you get off this bus? ______________________________
(Street & cross-street)

2. How often do you ride a TriMet bus/MAX/streetcar in a typical week? *(Check one box.)*

☐₁ 1 day a week or less ☐₂ 2 to 4 days a week ☐₃ Every weekday or more

3. What is the major reason you are using the bus for this one-way trip? *(Check one best answer.)*

☐₁ I do have a car but prefer to use TriMet ☐₂ I don't have a car because I prefer to use TriMet
☐₃ I don't have a car available for me to use ☐₄ I don't drive or don't know how to drive

4. How satisfied are you with your trip today on this bus?
Please answer using this 6-point scale where 1 means very dissatisfied and 6 means very satisfied. *(Circle one answer for each statement.)*

	Very Dissatisfied					Very Satisfied
a) Getting to the bus stop	1	2	3	4	5	6
b) Waiting for the bus	1	2	3	4	5	6
c) Riding on this bus	1	2	3	4	5	6
d) Your overall trip today	1	2	3	4	5	6

5. How satisfied are you in general with this bus route?
Please answer using this 6-point scale where 1 means very dissatisfied and 6 means very satisfied. *(Circle one answer for each statement.)*

	Very Dissatisfied					Very Satisfied
A) Close to home	1	2	3	4	5	6
B) Close to destination	1	2	3	4	5	6
C) Sidewalk connects to stop	1	2	3	4	5	6
D) Crossing street to stop is easy	1	2	3	4	5	6
E) Shelter is provided	1	2	3	4	5	6
F) Bench is provided	1	2	3	4	5	6
G) Frequency of buses	1	2	3	4	5	6
H) Times of day the route operates	1	2	3	4	5	6
I) Reliability of service	1	2	3	4	5	6
J) Seat available	1	2	3	4	5	6
K) Wait time for bus	1	2	3	4	5	6
L) Not over-crowded	1	2	3	4	5	6
M) Friendly drivers	1	2	3	4	5	6
N) Amount of time to reach destination	1	2	3	4	5	6
O) Seat comfort	1	2	3	4	5	6
P) Smooth ride	1	2	3	4	5	6
Q) Temperature inside bus is comfortable	1	2	3	4	5	6

6. Of the factors listed above in Question #5, please rank the ones that are the most important to you, starting with the most important, then listing the next most important, and so on. *(Write in the letter corresponding to each factor. If there are fewer than five factors that are important to you, leave the remaining lines blank. If a factor important to you is not listed, please write it in, instead of a letter.)*

Most important factor______

2nd most important factor______

3rd most important factor______

4th most important factor______

5th most important factor______

503-238-RIDE (7433) TTY 503-238-5811 trimet.org **Thank you** 4/04 would be easier to administer under crowded conditions. Exhibit 58 shows an example of the Phase 2 survey form.

In order to cover the different groups in the San Francisco Bay Area adequately, Spanish and Mandarin Chinese versions of the questionnaire were also produced.

On the Phase 2 survey form, surveyors wrote a unique bus trip ID number in the upper right-hand corner for all questionnaires collected from that one-way bus trip. This ID number was then used to tie in the individual questionnaire to a unique bus route, direction, and time period.

Survey Distribution

In Phase 1, surveyors worked in teams of two. Two teams were assigned to a given route in Portland and Virginia, while three teams were assigned in Broward County, due to the longer route length. The teams started during the a.m. peak hour (around 7 a.m.) and rode their assigned bus route back and forth, for approximately 4 hours. The surveyors rode the Portland and Virginia routes from end-to-end and rode the Broward County route for most of its length within the county (about three-quarters of its total length, which extends just over the county line to the north and several miles beyond the county line to the south).

On the bus, the first surveyor sat immediately behind the driver and was responsible for (1) handing out surveys and golf pencils as persons boarded the bus, (2) occasionally removing surveys and pencils from the collection envelopes, and (3) cleaning up any surveys or pencils that passengers might have dropped on the floor. Surveys were handed out in numerical order. The first surveyor also had self-addressed stamped envelopes to hand to passengers wishing to complete the survey later, as well as large-print versions of the survey for riders with visual impairments. TriMet also required that the first surveyor carry a TriMet-designed card that provided both printed and Braille information instructing riders with visual impairments to call TriMet's information line to complete the survey. For this survey, TriMet's operators were instructed to take the person's name, phone number, and a call-back time and to pass the information to the researchers to complete the survey. Although cards were handed out, no one called TriMet to participate in the survey.

Exhibit 58. Phase 2 Transit Survey Form.

SERVICE QUALITY SURVEY

Please take a few minutes to fill out this survey.
We want to know how satisfied you are with service on this bus.
When finished, please hand this form back to the survey taker.

1. Where did you get on this bus? ____________________
(Street & cross street)

2. Where will you get off this bus? ____________________
(Street & cross street)

3. How often do you ride Muni?

☐ 5 or more days per week ☐ 1 – 2 days per week
☐ 3 – 4 days per week ☐ Less than 1 day per week

4. Could you have used a car for this trip?

☐ Yes
☐ No

5. How satisfied are you with your trip today on this bus?
Please circle a number below for each answer, where
1 means very dissatisfied and
6 means very satisfied.

	←← **Dissatisfied**				**Satisfied** →→	
	Very dissatisfied					Very satisfied
a) Getting to the bus stop	1	2	3	4	5	6
b) Waiting for the bus	1	2	3	4	5	6
c) Riding on this bus	1	2	3	4	5	6
e) This bus trip overall	1	2	3	4	5	6

The second surveyor sat in the first seat on the right side of the bus and was equipped with forms listing all of the bus stops served by the route in each direction. This surveyor was responsible for recording the number of people getting on and off at each stop and for recording the last survey serial number handed out at each stop. One team per route also carried a GPS unit that generated a log file recording the bus' position and speed every second; the second surveyor was responsible for using it. A new log file was generated for each trip. The GPS unit used was tested in an automobile prior to use and worked as expected; however, when used on buses, the unit sometimes had problems receiving satellite signals. As a result, GPS data were not available for all bus trips. In Portland, the handheld GPS data were supplemented with archived data from TriMet's automatic vehicle location system.

For the Phase 2 surveys, one surveyor was assigned per door to each bus that was surveyed; for example, two surveyors were assigned to regular buses, while three surveyors were assigned to articulated buses. Surveyors handed out a questionnaire to each person boarding the bus. Surveyors also attempted to interview standing passengers, asking them questions while the bus was in motion; consequently, surveyors with multi-lingual capability were assigned to specific routes that carry large numbers of non-English-speaking passengers.

Exhibit 59 shows the number of surveys distributed and returned in each location. Not all returned surveys were filled out completely. For Phase 2, surveyors were unable to keep track of the number of surveys distributed due to the heavy workload on crowded buses.

Route Characteristics

Routes were selected to create variety in (1) particular route characteristics that previous research had determined to be important (e.g., the TCQSM's LOS factors), and (2) specific pedestrian environment characteristics not previously researched. In addition, the routes selected in Northern Virginia included urban street segments also being used by GMU for the automobile LOS element of this project.

Exhibit 59. Transit Survey Distribution.

Location (Route)	Distributed	Returned	Usable
Virginia (2B)	186	182	172
Virginia (38B)	181	166	154
Portland (14)	218	204	198
Portland (44)	268	262	255
Florida (18)	306	276	165
San Francisco Muni (1)	NA	NA	201
San Francisco Muni (14)	NA	NA	366
San Francisco Muni (30)	NA	NA	112
San Francisco Muni (38)	NA	NA	339
San Francisco Muni (38L)	NA	NA	153
AC Transit (51)	NA	NA	199
AC Transit (72)	NA	NA	239
AC Transit (72R)	NA	NA	101
AC Transit (218)	NA	NA	24
Total	NA	NA	2,678

In Northern Virginia, WMATA Route 2B starts in the dense urban portions of Arlington (Ballston-MU Metrorail) and travels past sprawling residential neighborhoods, golf courses, cemeteries, office parks, and strip commercial uses in Falls Church and Fairfax. Route 2B stops at several auto-oriented Metrorail stations (i.e., East Falls Church, Dunn Loring-Merrifield, and Vienna/Fairfax-GMU) before completing its trip at the Fair Oaks Shopping Center in Fairfax. Some peak-period trips operate as Route 2G, deviating to serve an AT&T office building, but otherwise serving the same route. The eastern half of the route is duplicated by Route 2C, which effectively doubles the service frequency on that portion of the route.

WMATA's Route 38B also starts at the Ballston-MU Metrorail station, but travels through the most dense, transit-oriented portions of Arlington, stopping near three Metrorail stations (i.e., Clarendon, Court House, and Rosslyn) surrounded by mixed uses and high-rise buildings, before crossing the Francis Scott Key Bridge into Washington's dense Georgetown neighborhood and ending at Farragut Square, just two blocks from the White House. Route 38B is the only all-day WMATA route crossing the Key Bridge, although one of the Georgetown Metro Connection routes also crosses the bridge.

In Portland, Route 14 is one of TriMet's most frequent bus routes (eight buses per hour peak, five buses per hour midday) and has one of the longest service spans. Route 14 runs from the I-205/Foster Road interchange in southeast Portland (no park-and-ride provided) into downtown Portland via the Hawthorne Bridge (a drawbridge) and then runs along the downtown bus mall to Union Station. East of downtown, the street frontage is primarily commercial or mixed-use office and commercial in multiple-story buildings. Some low- to medium-density multi-family residential buildings also front the streets served by the transit route. Past the immediate transit street frontage, land uses are primarily medium- to high-density single-family residential.

TriMet Route 44 connects Portland Community College's Sylvania campus in southwest Portland to downtown and Union Station via the bus mall, passing through the commercial districts of Multnomah Village and Hillsdale. Outside the commercial areas, land uses served by the route are a mix of medium-density single-family residential and low-density multi-family residential. A 1-mile section of the route south of Multnomah Village lacks sidewalks. The route is also one of many serving Portland State University at the south end of downtown. Service from Hillsdale into downtown is duplicated by several other routes, creating a better effective frequency.

TriMet Route 15, used for the pilot test, runs from the Parkrose/Sumner transit center, light rail station, and park-and-ride lot in northeast Portland south to Mall 205 (a small shopping center). The route continues west through downtown Portland (at right angles to the bus mall), past a hospital, and ends in northwest Portland. Alternate trips terminate in a residential area of northwest Portland or at Montgomery Park, a large office building (the surveyed trips went to Montgomery Park). Land uses vary along the route and include medium- to high-density single-family residential, low- to medium-density multi-family residential, and office and commercial uses.

In Broward County, Route 18 runs north-south the length of the county along U.S. 441, from the south edge of Palm Beach County to the Golden Glades park-and-ride lot in northern Miami-Dade County, where transit connections can be made for trips continuing south. Service is provided at 15-minute headways during peak and midday periods. A weekday peak-period limited-stop version of the route (Route 18LS, not surveyed) duplicates all but the very northern end of the route and operates at 45-minute headways.

Phase 2 sample selection was guided by the results of analysis of the Phase 1 data set. Based on that analysis, it was determined that the Phase 2 sample should be designed to round out the characteristics of the Phase 1 data set. In particular, we sought a sample that included routes with one or more of the following characteristics:

- Moderate to severe crowding, with load factors greater than 1;
- High-demand density;
- Frequent service;
- Operation on reserved bus lanes; and/or
- Low frequency.

The San Francisco Bay Area has two transit agencies that operate routes with these characteristics. The San Francisco Municipal Railway (Muni) operates service within the City and County of San Francisco, with over 800,000 boardings on an average weekday. The Alameda-Contra Costa Transit District (AC Transit) operates service in the East Bay; cities within its service area include Oakland, Berkeley, Richmond, Hayward, and Fremont.

For all routes surveyed on Muni and AC Transit, surveys were taken on bus trips in both directions during the AM peak and PM peak. The following routes were selected for the sample:

- The Muni 1 California, a trolley bus, operates from the San Francisco Financial District westbound through Chinatown, Pacific Heights, and Laurel Heights to the Inner Richmond district. Surveyors rode the bus only from the Financial District to Laurel Heights. The bus runs on between 8 and 9-minute headways during the peak periods.
- The Muni 14 Mission begins in the downtown Financial District and runs through the Mission District to Daly City. This is Muni's busiest route, carrying over 60,000 passengers on an average weekday. Although articulated buses are used on this route, buses are frequently crowded, with most passengers standing. This bus runs on a priority bus lane (buses and right turns only) along Mission St. to about 10th St., but the bus lane is frequently violated by cars.
- The Muni 30 Stockton, a trolley bus, runs from the Caltrain Depot at 4th and Townsend north through the Financial District, then through Chinatown and North Beach to the Marina District. Buses frequently bunch up; because it is a trolley bus, buses cannot pass each other. Buses move especially slowly through Chinatown, where there are large numbers of boardings and alightings. The bus operates on 9-minute headways during the peak periods.
- The Muni 38 Geary and 38L Geary Limited operate from the Transbay Terminal along Market St., then along Geary to western San Francisco. Past 33rd Avenue, the route splits into three branches. This is one of Muni's busiest routes, carrying about 60,000 passengers per day. Buses are articulated, but are frequently crowded with most passengers standing. Effective headways east of 33rd Avenue are between 4 and 8 minutes, depending on whether the local or limited service is used. The bus runs on dedicated priority bus lanes (buses and right turns only) from downtown to Van Ness Avenue, but these are frequently violated.
- AC Route 51 Broadway, one of the busiest routes on the AC Transit system, runs from Alameda (an island off of Oakland) through the Posey Tube through downtown Oakland, then north along Broadway and College Avenue to Berkeley, and then west to the western part of Berkeley. This route serves the UC Berkeley campus, so many of the riders are UC students or faculty. The bus operates on about 8-minute headways during the peak periods.
- AC Route 72 San Pablo runs along San Pablo Avenue from downtown Oakland along San Pablo Avenue through Berkeley to Hilltop Mall in Richmond. The 72 operates on 30-minute headways throughout the day, but service is paralleled by the 72M, which also operates on 30-minute headways on the part of the route that was surveyed.
- AC Route 72R San Pablo Rapid is a new rapid bus service that runs from downtown Oakland along San Pablo Avenue through Berkeley to Contra Costa College. Stops are spaced about every half mile. The bus operates on 12-minute headways throughout the day.
- AC Route 218 Thornton was chosen to provide a sample on a long-headway route (1 hour). The 218 runs from Ohlone College in Fremont to the Lido Faire shopping center in Newark.

Exhibits 60, 61, and 62 summarize key characteristics of the selected routes.

Exhibit 60. Route Characteristics—Phase 1.

Characteristic	Route				
	Virginia 2B	Virginia 38B	Portland 14	Portland 44	Florida 18
Peak frequency (bus/h)	2	4	8	4	4
Off-peak frequency (bus/h)	1	2	5	4	4
Maximum eff. frequency (bus/h)	4	7	38	38	5
Service span (h/day)	16.5	22	20.5	16	19.5
Stops with shelter (%)	13%	29%	34%	30%	23%
Stops with bench (%)	15%	26%	47%	41%	75%
Street width range (lanes)	2–9	1–7	2–6	1–6	5–9
Stops at traffic signals (%)	40%	68%	48%	40%	48%
Stops with sidewalks (%)	89%	99%	99%	81%	88%
Stops without legal crosswalks (%)	53%	19%	6%	9%	51%
Average load (p/bus)	11	14	10	16	**
Average maximum load (p/bus)	18	28	27	25	**
Maximum load (p/bus)	34	44	37	42	**

**Due to a data collection problem, loads cannot be calculated for all trips. A few surveyed trips had standing loads.

4.7 Representation of Survey Results By A Single LOS Grade

The automobile, transit, bicycle, and pedestrian surveys produced distributions of LOS ratings for any given condition. However, a distribution of LOS results for any given mode on any given street is less convenient for decisionmakers than a single-letter LOS grade as is customary in the HCM). The HCM does not report the distribution of LOS grades for a given situation. The HCM reports a single LOS grade for a given situation. This research project was, therefore, confronted with the issue of how to convert the distribution of LOS grades reported by the public into a single LOS grade for a given situation.

In statistics, various single-value measures can be used to represent a distribution. The two most common single-value measures are the "mean" and the "mode" of the distribution.

The mode is appealing, because it represents the most frequent LOS response of the public. However, the mode has one weakness, in that it is possible for a distribution with two "camel humps" to have two modes. It is possible for both humps to be an identical percentage of the total distribution, in which case, one cannot report a single LOS result.

The mean is appealing because it always results in a single LOS grade, regardless of the distribution. However the mean has a major weakness in that it can reach LOS A or LOS F only in the rare cases when there is almost complete agreement by the members of the public that the LOS is A or F. Even if most respondents pick LOS A or F, it takes few dissenters to drag the mean LOS from A or F (see Exhibit 63).

As shown for Distribution #1 in Exhibit 63, even when 50% of the people choose LOS A, the mean will still be 1.65, which is closer to 2.00 (LOS B) than to 1.00 (LOS A). The "mode" performs as desired for these example distributions, however; we have ruled it out because of its inability to resolve a tie.

The row labeled LOS 1 converts mean values to a letter grade using the same values of LOS A through LOS F that were used to compute the mean (see Exhibit 64). As can be seen, this approach cannot get LOS A for the mean of

Exhibit 61. Route Characteristics—Phase 2, San Francisco.

Characteristic	Route				
	1 California	14 Mission	30 Stockton	38 Geary	38 Geary Limited
Peak frequency (bus/h)	20	10	7	8	9
Off-peak frequency (bus/h)	10	7	7	8	9
Maximum eff. frequency (bus/h)	20	10	27	10	12
Service span (h/day)	20	24	20	24	14
Stops with shelter (%)	44	54%	44%	68%	84%
Stops with bench (%)	44	56%	44%	69%	86%
Street width range (lanes)	2 – 5	2 – 4	2 – 7	2 – 8	2 – 8
Stops at traffic signals (%)	58%	91%	54%	63%	75%
Stops with sidewalks (%)	NA	NA	NA	NA	NA
Stops without legal crosswalks (%)	2%	1%	1%	3%	0%
Average load (p/bus)	NA	NA	NA	NA	NA
Average maximum load (p/bus)	NA	NA	NA	NA	NA
Maximum load (p/bus)	NA	NA	NA	NA	NA

Exhibit 62. Route Characteristics—Phase 2, AC Transit.

Characteristic	Route			
	51 Broadway	72 San Pablo	72R San Pablo Rapid	218 Thornton
Peak frequency (bus/h)	8	4	5	1
Off-peak frequency (bus/h)	8	4	5	1
Maximum eff. frequency (bus/h)	8	4	5	1
Service span (h/day)	19	18	14	15
Stops with shelter (%)	28%	39%	74%	11%
Stops with bench (%)	51%	46%	75%	15%
Street width range (lanes)	2 – 7	2 – 5	2 – 5	2 – 6
Stops at traffic signals (%)	67%	60%	85%	60
Stops with sidewalks (%)	NA	NA	NA	NA
Stops without legal crosswalks (%)	0%	8%	4%	18%
Average load (p/bus)	NA	NA	NA	NA
Average maximum load (p/bus)	NA	NA	NA	NA
Maximum load (p/bus)	NA	NA	NA	NA

distribution #1, but otherwise, performs reasonably for the other five example distributions.

The row labeled LOS 2 converts the mean values to a letter grade using a shifted set of thresholds that divide at the midpoint between each LOS value. Unfortunately, this approach results in Distribution #6 being converted to LOS E, instead of the desired F and does not solve the problem of producing LOS B for Distribution #1, when LOS A is the desired result.

The row labeled LOS 3 shows the results when a compressed range of thresholds is used to convert the mean values to letter grades. The compressed range squeezes together the thresholds for LOS B to LOS E, so that wider ranges are available for LOS A and LOS F. Under this scheme, LOS A ranges from a mean of 1.0 to a mean of 2.0; LOS F ranges from a mean of 5.0 to 6.0. These larger ranges for the extreme LOS grades ensure that extreme LOS grades will be output for distributions where a large portion of the responses are at the extreme LOS grades.

The LOS3 threshold scheme was tested on the auto video clip results and was found to produce a reasonable range of LOS A through F results for the mean LOS values for the video clips that were representative of the distribution of the reported LOS results. This threshold scheme was adopted for reporting the data collection results and for reporting single-letter grade results from the various LOS models developed under this research.

Exhibit 63. Example Distributions and Mean of Level of Service.

LOS	Dist 1	Dist 2	Dist 3	Dist 4	Dist 5	Dist 6
A	**50%**	25%				
B	35%	**50%**	25%			
C	15%	25%	**50%**	25%		
D			25%	**50%**	25%	15%
E				25%	**50%**	35%
F					25%	**50%**
Mean	1.65	2.00	3.00	4.00	5.00	5.35
Mode	1	2	3	4	5	6
LOS 1	B	B	C	D	E	F
LOS 2	B	B	C	D	E	E
LOS 3	A	B	C	D	E	F

Exhibit 64. LOS Mean Value Threshold Schemes.

LOS	Numerical Value	LOS 1 Straight Thresholds	LOS 2 Thresholds Shifted to Midpoints	LOS 3 Compressed Ranges
A	1	Mean ≤ 1.00	Mean ≤ 1.50	Mean ≤ 2.00
B	2	> 1.00 to ≤ 2.00	> 1.50 to ≤ 2.50	> 2.00 to ≤ 2.75
C	3	> 2.00 to ≤ 3.00	> 2.50 to ≤ 3.50	> 2.75 to ≤ 3.50
D	4	> 3.00 to ≤ 4.00	> 3.50 to ≤ 4.50	> 3.50 to ≤ 4.25
E	5	> 4.00 to ≤ 5.00	> 4.50 to ≤ 5.50	> 4.25 to ≤ 5.00
F	6	Mean > 5.00	Mean > 5.50	Mean > 5.00

CHAPTER 5

Auto LOS Model

5.1 Model Development

Identification of Key Variables

A correlation analysis was performed to determine what relationships may exist between the dependent variable (i.e., individual participant ratings of LOS) and a dataset of 78 independent variables represented in the video clips or transformations of said variables (i.e., log of mean travel speed). The correlation analysis revealed that no less than 69 variables had a statistically significant relationship with individual participant ratings of LOS.

Exhibit 65 summarizes the correlation analysis, including Kendall's tau rank correlation coefficients. Some variables have not been included in order to reduce the size of the table. For example, transformations of variables have not been included because they tend to have the same or similar tau rank correlation coefficient patterns and significance values. Care was taken in selecting explanatory variables included in the modeling effort so as to avoid including variables that were highly correlated with each other.

Exhibit 66 illustrates the correlation analysis done of the explanatory variables to understand the relationships between these variables. In this table, the tau rank correlation coefficients are shown for correlations between space mean speed and the previously listed explanatory variables. In this table, all significance values are <0.10, meaning the relationships are statistically significant at the 90% level.

Linear Regression Tests

Linear regression techniques were first explored to determine if a multiple linear relationship might exist that could estimate the mean rating obtained for each video clip shown in Phase I and/or II of the study.

Independent variables to be used to estimate the dependent variable (mean clip rating) were selected from the larger set of explanatory variables. This was done by controlling for redundant explanatory variables (e.g., average travel speed and number of stops) and by retaining those explanatory variables that were highly correlated with the mean clip rating. The explanatory variables included in the stepwise regression exercise were as follows:

- Space mean speed,
- Number of stops,
- Stops per mile,
- Presence of median,
- Presence of exclusive left-turn lane,
- Presence of trees rating, and
- Pavement quality rating.

Forward stepwise regression techniques were used to allow for the inclusion of variables into the model only if they could increase the ability of the model to predict the dependent variable shown through the increase in R-square value. The results of the stepwise multiple linear regression are shown in Exhibit 67. The adjusted R-square value for the overall model is 0.673.

The model is

$$\begin{aligned} \textit{Mean Auto LOS} = {} & 3.8 - 0.530(\textit{Stops}) - 0.155(\textit{Median}) \\ & + 0.355(\textit{Left-Turn Lane}) + 0.098(\textit{Trees}) \\ & + 0.205(\textit{Pavement Quality}) \qquad \text{(Eq. 9)} \end{aligned}$$

Where

Mean Auto LOS = 6.0 for LOS A and 1.0 for LOS F

Stops = number of times in video clip that auto speed drops below 5 mph.

Median = 3 if raised median (curbs between opposing traffic streams), 2 if two-way left-turn lane, 1 if no opposing traffic stream (one-way street), 0 if no separation between opposing traffic streams.

Left-Turn Lane = one if present, zero otherwise. Exclusive left-turn lane can be of any length or

Exhibit 65. Correlation Between Explanatory Variables and LOS Ratings.

Variable	tau Rank Correlation Coefficient	Significance p-value
Space Mean Speed	0.317	0.000
Total Travel Time	-0.315	0.000
Lane Width	0.307	0.000
Number of Stops per Mile	-0.307	0.000
Sign Quality	0.268	0.000
Tree Presence	0.248	0.000
Sidewalk Width	-0.244	0.000
Has Ex Left-Turn Lane	0.223	0.000
Pedestrian Presence	-0.218	0.000
Number of Signals per Mile	-0.217	0.000
Control Delay per Mile	-0.210	0.000
Speed Limit	0.198	0.000
Median Presence	0.175	0.000
Stops per Signal	-0.159	0.000
Lane Marking Quality	0.110	0.000
Median Width	0.107	0.000
Variation in Speed	-0.084	0.000
Number of Through Lanes	-0.065	0.003
Separation Between Sidewalk and Travelway	0.055	0.010

width. Two-way left-turn lanes do not count as exclusive left-turn lanes.

Trees = 3 if many, 2 if some, 1 if few or none

Pavement Quality = 4 if new, 3 if typical, 2 if cracked, 1 if poor.

The R-square statistic for this model equals 0.673, meaning 67 percent of the variation in mean participant ratings can be estimated by the model; however, several variables included in the model do not contribute significantly to the overall model predictive power, as indicated by their high *p*-values.

To address the inclusion of variables that are not statistical contributors to the model, another regression model was developed that included only the number of stops and the presence of an exclusive left-turn lane, those variables which were significant in Model 1. This new model's details are provided in Exhibit 68.

In this model each of the two variables, number of stops, and presence of an exclusive left-turn lane were significant at the 0.05 level resulting in the following:

$$\text{Mean Auto LOS} = 4.327 - 0.622\,(\text{Stops}) + 0.293\,(\text{Left Turn Lane}) \quad \text{(Eq. 10)}$$

Where

Mean Auto LOS = 6.0 for LOS A and 1.0 for LOS F

Stops = Number of times in video clip that auto speed drops below 5 mph.

Exhibit 66. Correlation Between Space Mean Speed and Other Explanatory Variables.

Variable	tau Rank Correlation Coefficient
Space Mean Speed	1.00
Total Travel Time	0.617
Lane Width	-0.694
Number of Stops per Mile	0.270
Sign Quality	0.442
Tree Presence	0.474
Sidewalk Width	-0.423
Has Ex Left-Turn Lane	0.264
Pedestrian Presence	-0.445
Number of Signals per Mile	-0.270
Control Delay per Mile	-0.721
Speed Limit	0.381
Median Presence	0.147
Stops per Signal	-0.462
Lane Marking Quality	0.111
Median Width	0.117
Variation in Speed	-0.287
Number of Through Lanes	-0.222
Separation Between Sidewalk and Travelway	0.104

Exhibit 67. Multiple Linear Regression Model #1.

Variable	Standard Coefficient	t-Statistic	Statistical Significance (p-value)
Constant	3.8	9.832	0.00*
Number of Stops	-0.530	-4.154	0.00*
Median Presence	-0.155	-0.898	0.377
Presence of Ex. Left-Turn Lane	0.355	1.903	0.067*
Tree Rating	0.098	0.816	0.421
Pavement Quality	0.205	1.556	0.130

*Statistically Significant at the 0.10 confidence interval

Left-Turn Lane = Presence of exclusive left-turn lane at all intersections. Equals one if present, zero otherwise. Exclusive left-turn lane can be of any length or width.

This second model has an adjusted R-square value of 0.647, slightly inferior to Model 1.

Similar model formats were attempted using average space mean speed as the primary predictor of mean participant rating; however, the adjusted R-Square values were lower at 0.545, meaning only 54.5% of the variation in mean participant ratings could be explained by the model. For this model, explanatory variables space mean speed, presence of an exclusive left-turn lane, and tree rating were included in the stepwise regression analysis. In this case, tree rating did not contribute significantly to the prediction power of the model and so was removed. Exhibit 69 contains statistical information for Model 3.

The end result is a model of the following form

$$\text{Mean Auto LOS} = 2.673 + 0.479\,(\text{Speed}) + 0.403\,(\text{Left-Turn Lane}) \qquad \text{(Eq. 11)}$$

Where

Mean Auto LOS = 6.0 for LOS A and 1.0 for LOS F

Speed = average space mean speed in mph.

Left-Turn Lane = Presence of exclusive left-turn lane at all intersections. Equals one if present, zero otherwise. Exclusive left-turn lane can be of any length or width.

This model has an adjusted R-square value of 0.545, inferior to Models 1 and 2. The lowest value that this model can produce is 2.673, the value of the constant. Thus the LOS could never be below LOS E.

Limitations of Linear Regression Modeling

Linear regression techniques are not particularly the best model specification choice when modeling ordered response variables in that linear regression models attempt to determine the best-fitting linear equation according to the least-square criterion, such that the sum of the squared deviations of the predicted scores from the observed scores is minimized to give the most accurate prediction. This assumes that, for a measured change in the explanatory variables, there is a measured linear change in the dependent variable, namely the mean participant rating. Linear regression models also predict a continuous variable, which is different than what was asked of participants in the study. For example, linear regression models will also predict values such as 3.42 LOS, lying between LOS C and D.

These limitations led the research team to investigate the use of cumulative logistic regression, which can predict the

Exhibit 68. Multiple Linear Regression Model #2.

Variable	Standard Coefficient	t-Statistic	Statistical Significance (p-value)
Constant	4.327	16.428	0.00*
Number of Stops	-0.622	-5.152	0.00*
Presence of Ex. Left-Turn Lane	0.293	2.427	0.021

*Statistically Significant at the 0.05 confidence interval

Exhibit 69. Multiple Linear Regression Model #3.

Variable	Standard Coefficient	t-Statistic	Statistical Significance (p-value)
Constant	2.673	10.483	0.00*
Space Mean Speed	0.479	3.657	0.01*
Presence of Ex. Left-Turn Lane	0.403	3.075	0.004*

*Statistically Significant at the 0.05 confidence interval probability of responses within each LOS based on a combination of explanatory variables. This characteristic also allowed the research team to make use of the nearly 1,650 observations contained in the modeling database rather than just 35 mean estimates of LOS (1 mean LOS for each video clip shown), and to predict the discrete outcome (i.e. 1,2, . . ., 6) as generated from the video lab surveys.

Cumulative Logistic Regression

For the auto LOS survey, the overall ratings (RatingNum) have a hierarchical ordering that varies from 1 (worst rating, or LOS F) to 6 (best rating, or LOS A). The discrete nature of RatingNum rules out the use of ordinary Linear Regression, because it requires the response to be a continuous variable. Cumulative logistic regression addresses the issue of modeling discrete variables with hierarchical ordering.

Consider the following cumulative probability $P(Y \le j \mid \mathbf{x})$ and define the logistic model for this probability as

$$Ln\frac{P(Y \le j \mid x)}{1 - P(Y \le j \mid x)} = \beta'(x) \qquad \text{(Eq. 12)}$$

In general, $P(Y = j \mid \mathbf{x}) = 1 - P(Y \le j - 1 \mid \mathbf{x})$, so estimated probabilities for all scores can be obtained. The vector β' represents the vector of coefficients for both LOS ranges (there are $6 - 1 = 5$ such intercept coefficients designated as α's) as well as the coefficients of the independent variables considered in the model (designated as β's). Equation 12 can be rewritten as

$$P(Y \le j \mid \mathbf{x}) = \frac{\exp(\beta'\mathbf{x})}{1 + \exp(\beta'\mathbf{x})}\mathbf{(3)} \qquad \text{(Eq. 13)}$$

Each cumulative probability has its own intercept α_j; the values of α_j are increasing in j since $P(Y \le j \mid \mathbf{x})$ increases in j for fixed $\mathbf{x}$. The model assumes the same effects $\beta_{tree\_presnce}$, $\beta_{stops\_per\_milet}$ and $\beta_{Pres\_\_Of\_Ex\_\_LT\_Lane}$ for each j.

In order to have an appropriate interpretation of the intercept values, consider Model 3 for two scores j and k with $j < k$ and assume values = 0 for the two dummies tree_presence and Pres__Of_Ex__LT_lane. After some algebraic manipulations we have

$$P(Y \le k \mid \text{stops\_per\_mile}) = P(Y \le j \mid \text{stops\_per\_mile} + (\alpha_k - \alpha_j) / \beta). \qquad \text{(Eq. 14)}$$

Cumulative probability for j is the same as the cumulative probability for k but evaluated at a stops_per_mile value displaced by an amount dependent on the positive difference between intercepts at score j and k, and the parameter β.

Exhibit 70 illustrates this model with increasing values of each α_j and positive value of β for stops_per_mile. The model coefficients, estimated using the Maximum Likelihood estimation methods, and their significance are shown in Exhibit 71.

What the increasing value of the intercept guarantees in this case is that for each (integer) value of RatingNum the sequence of cumulative probabilities for a certain value l of stops_per_mile are in the right order, meaning that,

$$\begin{aligned} &P(Y \le 1 \mid stops\_by\_mile = l) \le P(Y \le 2 \mid stops\_by\_mile = l) \\ &\le P(Y \le 3 \mid stops\_by\_mile = l) \le P(Y \le 4 \mid stops\_by\_mile = l) \\ &\le P(Y \le 5 \mid stops\_by\_mile = l) \le 1 \end{aligned} \qquad \text{(Eq. 15)}$$

A positive slope is evident in Exhibit 70 as the increment in the cumulative probability for a particular RatingNum score when stops_per_mile value increases. The difference between successive curves for RatingNum scores determines the probability $P(Y = j \mid \text{stops\_per\_mile})$ for an individual RatingNum score given a fixed value of stops_per_mile. For instance, the value of $P(Y \le 1) = P(Y = 1)$ is higher when stops_per_mile = 18 than when stops_per_mile = 1 and the value of $P(Y = 5) = P(Y \le 5) - P(Y \le 4)$ is higher when stops_per_mile = 1 than for stops_per_mile = 18, so it appears that, with higher probability, high ratings in LOS are given to trips with fewer stops per mile. Also shown in the exhibit are the marginal probabilities of the various levels of service (A to F) when the number of stops per mile is fixed at 2.

Best Candidate Auto LOS Models

Preliminary modeling analysis has resulted in two fairly strong models, one which uses number of stops per mile and the other which uses average space mean speed as the primary explanatory variable. Both models perform well. Both models are presented with “trees” or “no trees” options. The recommended models are shown in Exhibits 72 through 74.

The Pearson Correlation measures the ability of each model to reproduce the observed video clip ratings of level of service. A higher value indicates a better model fit. The highest possible value is 100%.

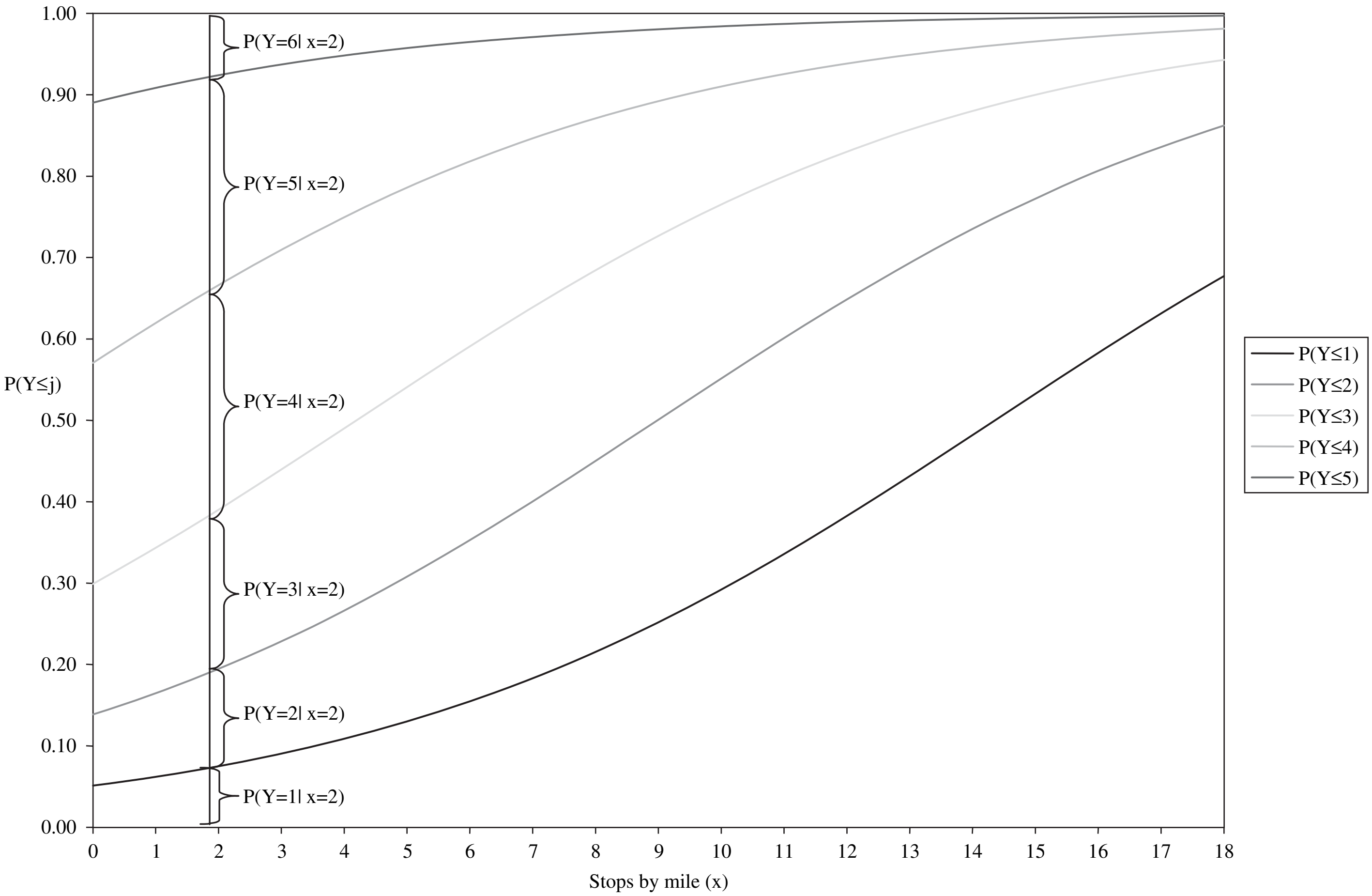
The Akaike Information Criterion (AIC) represents how close fitted values are to actual values taking into account the number of parameters included in each model (Agresti, 2002 [**97**]). Lower values indicate a superior model of the data.

Model 4 (stops per mile, presence of an exclusive left-turn lane and presence of trees) reported the lowest AIC measure and the highest Pearson correlation.

Performance of Candidates

A preliminary analysis of the ability of Models 4, 5, and 6 to predict the distribution of ratings of LOS as reported by participants was also undertaken. (The performance of Model 7 is presented in a later section describing refinement options for the recommended Auto LOS Model.)

Exhibit 70. Example Cumulative Logit Distribution of LOS.



Because the strength of the cumulative probability models lies in their ability to predict the distribution of LOS ratings for a particular combination of explanatory variables, the models were tested to determine their ability to accurately predict a distribution of responses as compared with those collected at the four study sites. One-third of the auto response dataset was reserved to test the fit of various models developed in this study and was not used in the model calibration. A subset of four clips was chosen to be shown in each of the four study sites in Phase II of the study. These four clips resulted in the largest number of observations in the test dataset, so only these four clips have been tested with Models 4, 5, and 6. The remaining clips in the test database do not have enough observations to develop a robust distribution of response data. Clips 2, 15, 52, and 56 are discussed in the following analysis.

Exhibits 75 through 78 compare the observed LOS rating distributions to those predicted by Model 4 (Stops/Mile; left-turn lane presence; tree presence index), Model 5 (Space Mean Speed; median presence index; tree presence index)

Exhibit 71. Maximum Likelihood Estimates for Model #4.

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept	1	1	-2.9189	0.2270	165.4053	<.0001
Intercept	2	1	-1.8273	0.2075	77.5198	<.0001
Intercept	3	1	-0.8529	0.2009	18.0246	<.0001
Intercept	4	1	0.2832	0.2005	1.9951	0.1578
Intercept	5	1	2.0937	0.2091	100.3006	<.0001
stops_per_mile		1	0.2033	0.0184	122.3357	<.0001
Pres__Of_Ex__LT_Lane		1	-0.5218	0.1111	22.0627	<.0001
Tree_Presence		1	-0.3379	0.0612	30.4761	<.0001

Parameters for Cumulative Regression Model Applied to Auto LOS—Stops per Mile Model– Model 4

Exhibit 72. Recommended Auto LOS Models.

Parameter	Model 4	Model 5	Model 6	Model 7
Intercept LOS E, Alpha1=	-2.92	-0.73	-3.80	-1.19
Intercept LOS D, Alpha2=	-1.83	0.28	-2.70	-0.20
Intercept LOS C, Alpha3 =	-0.85	1.21	-1.74	0.71
Intercept LOS B, Alpha4=	0.28	2.32	-0.62	1.80
Intercept LOS A, Alpha5=	2.09	4.16	1.16	3.62
Stops Per Mile, Beta1 =	0.20		0.25	
Presence of Left-Turn Lanes, Beta2 =	-0.52		-0.34	
Mean Speed (mph), Beta1 =		-0.063		-0.084
Median Presence (0-3), Beta2 =		-0.33		-0.22
Presence of Trees, Beta3 =	-0.34	-0.42		
Pearson Correlation=	79%	76%	77%	N/A
Akaike Information Criterion (AIC)	4944.0	5034.1	5022.8	5076.4

Exhibit 73. Test Clip Characteristics.

Clip Number	Number of Stops/Mile	Average Space Mean Speed (mph)	Median Presence (0-No 1-One-way Pair 2-TWCLTL 3-Raised	Ex. Lt.-Turn-Lane Presence (0-No 1-Yes)	Tree Presence (1-Few 2-Some 3-Many)	HCM LOS
2	0	34.5	3	1	2	A=6
15	6	7.86	3	1	1	F=1
52	7	7.9	0	0	1	E=2
56	2	23.1	3	1	3	C=4

Exhibit 74. Correlation Coefficients of Auto LOS Models.

Models Compared	Pearson Correlation Coefficient
HCM LOS to Mean Observed LOS	0.465
Mean Observed LOS to Mean LOS – Model 4	0.787
Mean Observed LOS to Mean LOS – Model 5	0.764
Mean Observed LOS to Mean LOS – Model 6	0.770

Exhibit 75. Evaluation of Models Against Clip 2 Ratings.

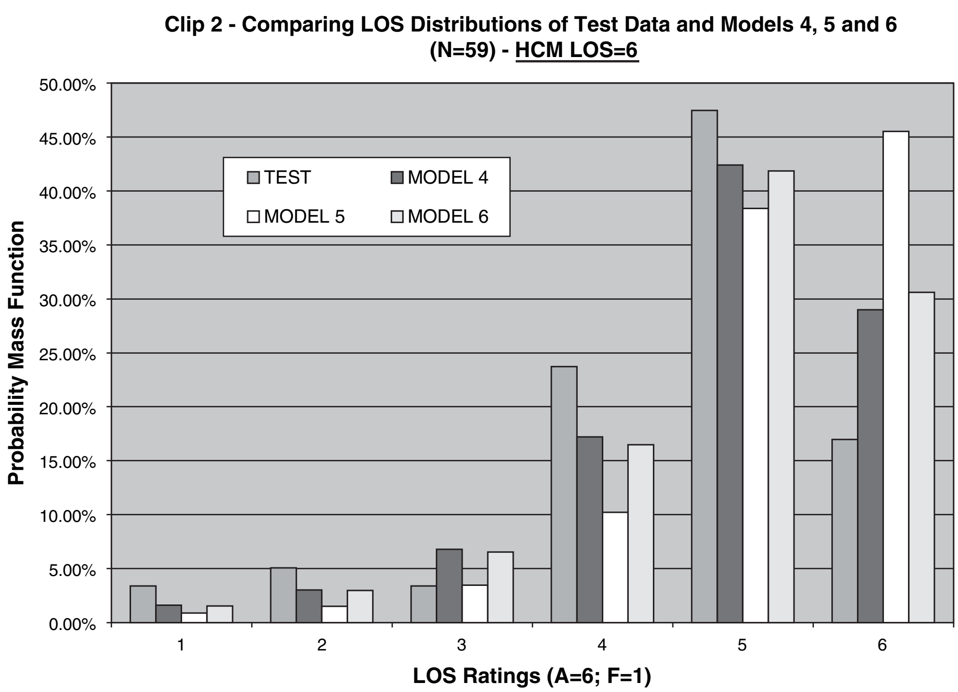
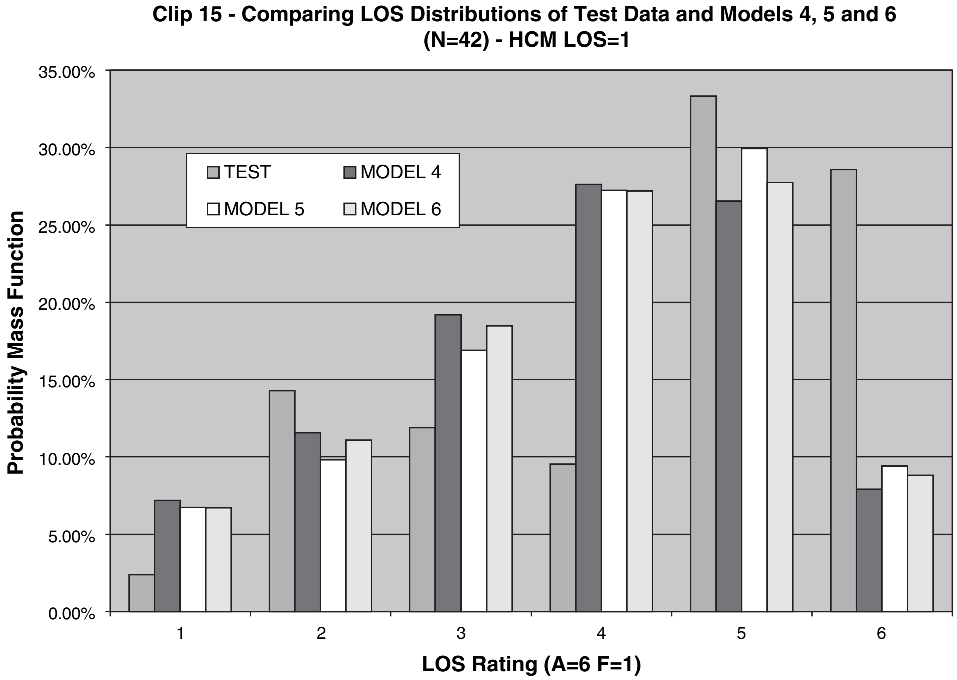


Exhibit 76. Evaluation of Models Against Clip 15 Ratings.



and Model 6 (Stops per mile; left-turn lane presence) for the four video clips. Exhibit 73 lists the conditions depicted in each of the four clips and the current HCM-estimated LOS.

Overall the models appear to track comparatively well with each other and with the data, in that there is a general increase/decrease in the estimation of LOS probability. Model 4 has slightly higher predictive power—it tends to track slightly closer to the test dataset represented by the periwinkle bar. For Clip 15, there is a definite difference between the HCM LOS of F and the distribution of LOS as provided by the study participants, which is shifted toward the right, meaning higher LOS ratings. In this clip, there are many stops along a short arterial, however, there is only low to moderate traffic congestion so that the test vehicle is always in the first position of the queue

Exhibit 77. Evaluation of Models Against Clip 52 Ratings.

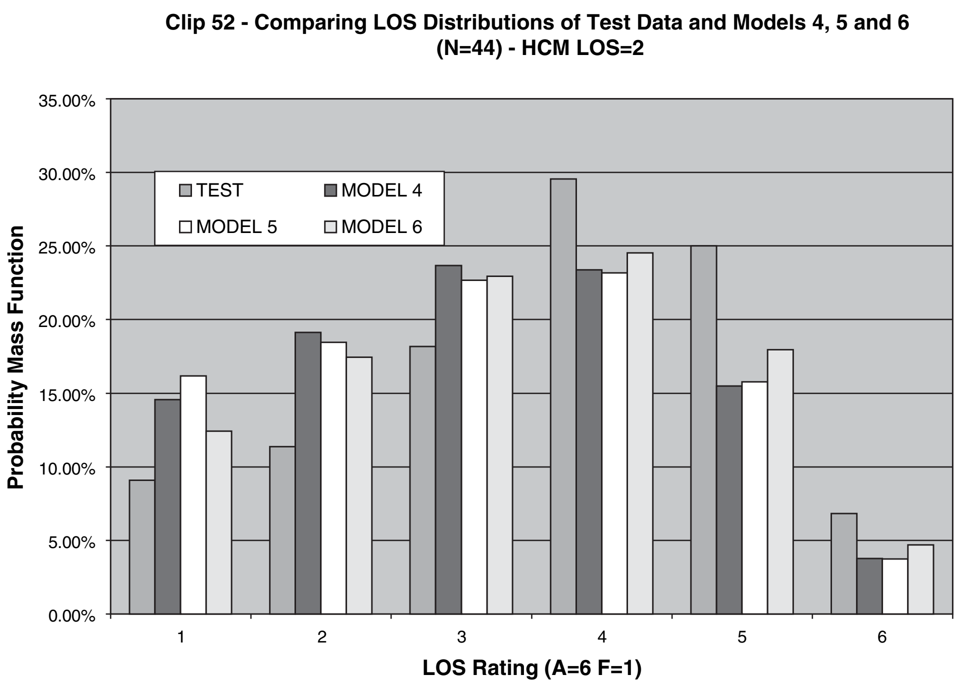
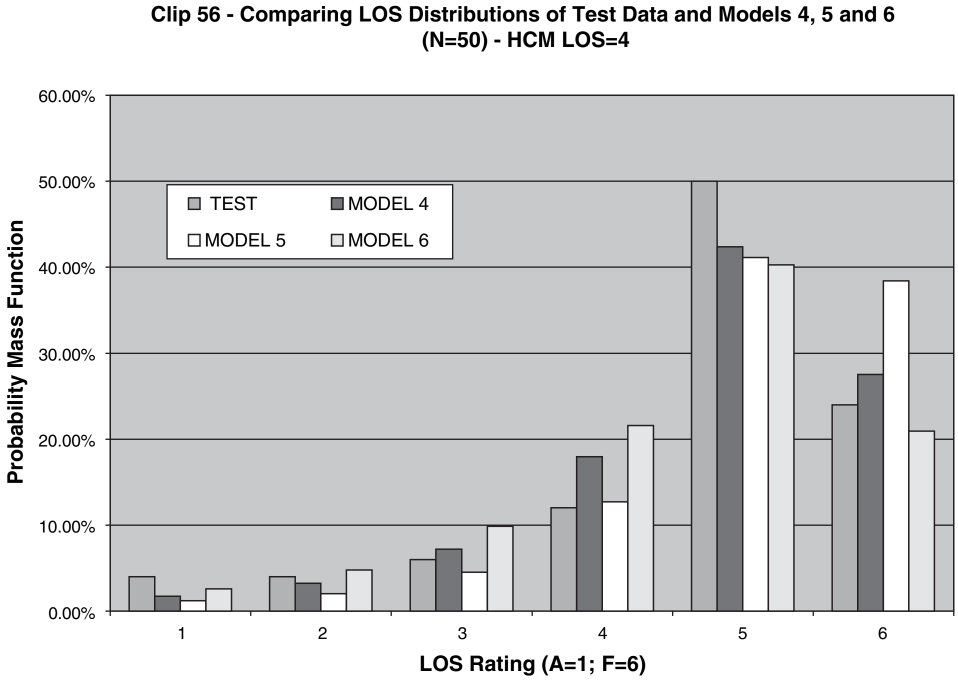


Exhibit 78. Evaluation of Models Against Clip 56 Ratings.



at each signal. In addition, it is a relatively clean and newly built out area in the Washington, DC, suburb of Arlington, VA. This combination of factors may have led participants to rate the video higher, despite the overall low space mean speed of 7.86mph and the high number of stops (6/mile).

Comparing the mean LOS as observed, the HCM LOS, and the model performance for Models 4, 5, and 6 we find that the HCM overall tended to underpredict the mean LOS as observed in the video laboratories. Model 6 also tends to underpredict mean observed LOS.

A correlation analysis of the various models and the test dataset shows that Models 4, 5, and 6 all have superior correlation to the mean video clip ratings than the HCM (see Exhibit 74).

Essentially the models all show a positive correlation, in that the compared models track the same in the positive or negative direction. The current HCM LOS method can only explain approximately 46 percent of the variation in mean observed LOS ratings. The three models developed for this study all perform much better and can explain, on average, approximately 75 percent of the variation in mean observed LOS ratings. The best fitting model is Model 4, which uses stops per mile, presence of an exclusive left-turn lane and the presence of trees to estimate the observed LOS ratings.

5.2 Recommended Auto LOS Model

The recommended auto LOS model (Model 6 above) predicts the *average* degree of satisfaction rating for the facility, where LOS A is "very satisfied" and LOS F is "very dissatisfied."

$$AutoLOS = Mean\ (LOS) \qquad \text{(Eq. 16)}$$

The average or "mean" LOS rating is the sum of the probabilities of an individual giving a facility a given LOS rating multiplied by the numerical equivalent of that LOS rating (J) (worst = 1, best = 6).

$$Mean(LOS) = \sum_{J=1}^{6} \Pr(LOS = J) * J \qquad \text{(Eq. 17)}$$

Where
J = 1 for the worst LOS rating and 6 for the best LOS rating.

The Mean LOS number is converted to a mean letter grade for the facility according to Exhibit 79.

The numerical thresholds for converting the mean score to the mean LOS letter grade differ from the scores (J) used to compute the mean score. Section 4.7 explained why different thresholds are used to convert the mean result to a letter grade.

The probability that a person will rate a given facility as exactly LOS J is computed by subtracting the cumulative probability of

Exhibit 79. Auto LOS Thresholds for Mean Numerical Scores.

LOS	Mean Numerical Score
A	≤ 2.00
B	>2.00 and ≤ 2.75
C	>2.75 and ≤ 3.50
D	>3.50 and ≤ 4.25
E	>4.25 and ≤ 5.00
F	> 5.00

giving the facility a lower LOS rating from the cumulative probability of giving the facility a LOS J rating or worse.

$$\Pr(LOS = J) = \Pr(LOS \le J) - \Pr(LOS \le J - 1) \qquad \text{(Eq. 18)}$$

The probability that a person will rate a given facility as LOS J or worse is given by the ordered cumulative logit model as shown below:

$$\Pr(LOS \le J) = \frac{1}{1+\exp(-\alpha_{(J)} - \sum_k \beta_k x_k)} \qquad \text{(Eq. 19)}$$

Where

Pr(LOS<=J) = Probability that an individual will respond with a LOS grade J or worse.

exp = Exponential function.

α_J = Alpha, Maximum numerical threshold for LOS grade J (see Exhibit 80).

β_K = Beta, Calibration parameters for attributes (see Exhibit 80).

X_K = Attributes (k) of the segment or facility (see Exhibit 80).

Two ordered cumulative logit models are recommended, both using the same form.

Model 1, derived from a statistical analysis of the video lab data, predicts auto LOS as a function of the number of stops per mile and the presence of exclusive left-turn lanes.

Model 2 was created to provide a speed-based model option for auto LOS. Model 2 predicts auto LOS as a function of the percent of free-flow speed and the type of median. The parameters for this model were first derived statistically from the video lab data. The resulting model, however, did not produce a full LOS A to LOS F range of results for the streets in the video lab sample. Given that public agencies may be reluctant to adopt a LOS model that cannot predict LOS A, the LOS intercept values for the model were modified manually to obtain a full LOS range of results for the streets in the video clip sample while attempting to maintain as high a match percentage with the video lab results as possible.

Model 1 provides a greatly superior statistical fit with the video lab data, however; this model does not produce LOS A for the streets contained in the video lab sample. Model 2 provides an inferior statistical fit with the data, but provides numerous LOS A results for the streets in the video lab sample. Both models predict LOS F for one or more of the streets in the video lab sample.

The attribute, stops per mile, is the number of times a vehicle decelerates from a speed above 5 mph to a speed below 5 mph, divided by the length of the urban street segment under consideration.

The attribute, Left-Turn-Lane Presence, takes on the following values:

- 1 if exclusive left-turn lane at intersections,
- 0 if not.

If the exclusive left-turn lanes do not provide sufficient storage for left-turning vehicles, then the number of stops per mile would be affected, which would, in turn, adversely affect the perceived level of service.

The attribute, Percent Speed Limit, is the ratio of the actual average speed (distance traveled divided by the average travel time for the length of the arterial including all delays) to the posted speed limit for the street.

The attribute, Median Type, is equal to

- 0 if no median,
- 1 if one-way street,
- 2 if a painted median is present, and
- 3 if a raised median is present.

The threshold values, α_j, and the attribute equation coefficients, β_k, of the ordered cumulative logit function are calibrated using the maximum likelihood estimation (MLE) process applied to paired data of facility characteristics and perceived LOS collected from people participating in the video laboratory surveys.

Exhibit 80. Alpha and Beta Parameters for Recommended Auto LOS Models.

Parameter	Model 1	Model 2
Alpha Values		
Intercept LOS E =	-3.8044	1.00
Intercept LOS D =	-2.7047	2.00
Intercept LOS C =	-1.7389	2.50
Intercept LOS B =	-0.6234	3.00
Intercept LOS A =	1.1614	4.00
Beta Values		
Stops/Mile=	0.2530	N/A
Left-Turn-Lane Presence (0-1), =	-0.3434	N/A
Percent Speed Limit	N/A	-5.74
Median Type (0,1, 2, 3)	N/A	-0.39

5.3 Performance of Auto LOS Models

Exhibit 81 shows how the mean LOS values produced by the recommended auto LOS model compare with the mean LOS values reported by the video lab participants. The HCM-predicted LOS is included as well. The HCM matched the video labs 26% of the time, while the proposed auto LOS Model 1 (stops) matched the video labs 69% of the time. The alternate proposed auto LOS Model 2 (speed) matched 37% of the video clip mean LOS ratings.

Model 2 ranges from LOS A to F, while Model 1 ranges from LOS B to F. Model 1 fits the video clip data better but does not achieve LOS A for the streets in the video clip sample. Model 2 has a significantly poorer fit with the data (but still better than the HCM); however, it does produce LOS A for nine of the streets in the video clip sample.

Several different sections or time periods of the same street were used for many of the clips.

Exhibit 81. Evaluation of Proposed Auto LOS Models.

Clip #	Street	Art Class	Spd Lim (mph)	Actual (mph)	Stops (stps/mi)	Left Ln (%)	Med (1,2,3)	Video LOS	HCM LOS	Model 1 LOS	Model 2 LOS
61	Rt 50	1	50	28	1.4	100%	0.00	A	C	B	C
56	Sunset Hills Rd	2	40	23	2.0	100%	3.00	A	C	B	A
2	Gallows Road	3	35	35	0.0	100%	3.00	B	A	B	A
65	Lee Hwy	2	40	36	0.0	100%	2.00	B	A	B	A
63	Rt 50	1	50	42	0.0	100%	3.00	B	A	B	A
5	Wilson Blvd	3	35	30	0.0	100%	3.00	B	B	B	A
62	Rt 50	1	50	37	0.0	100%	0.00	B	B	B	A
13	Washington Blvd	3	35	25	0.0	0%	0.00	B	B	B	A
7	Wilson Blvd	3	35	20	0.0	100%	1.00	B	C	B	B
54	Lee Hwy	2	40	25	3.3	100%	2.00	B	C	B	A
53	Prosperity	2	40	19	1.7	100%	3.00	B	D	B	B
6	Clarendon	3	35	18	2.3	100%	1.00	B	D	B	B
10	Washington Blvd	3	35	17	3.8	0%	0.00	B	D	C	C
20	Rt 50	1	50	16	1.8	100%	3.00	B	E	B	C
64	Rt 50	1	50	20	2.0	100%	3.00	B	E	B	B
58	Sunrise Valley Rd	2	40	11	1.7	100%	3.00	B	F	B	C
1	Rt 234	1	50	15	2.0	100%	3.00	B	F	B	C
29	Rt 234	2	40	23	2.0	100%	3.00	C	C	B	A
19	23rd St	4	30	16	5.8	0%	0.00	C	C	C	C
12	Wilson Blvd	3	35	14	4.3	0%	0.00	C	D	C	D
60	Lee Hwy	2	40	15	2.0	100%	2.00	C	E	B	C
21	Rt 50	1	50	20	4.0	100%	3.00	C	E	C	B
8	Wilson Blvd	3	35	14	4.1	100%	1.00	C	E	C	C
52	M St	4	30	8	7.3	0%	0.00	C	E	D	E
55	Braddock Rd	2	40	13	2.2	100%	3.00	C	F	B	C
59	Sunset Hills Rd	2	40	12	4.9	0%	0.00	C	F	C	E
15	Glebe Road	2	40	8	6.0	100%	3.00	C	F	C	D
14	Glebe Road	2	40	11	6.0	100%	3.00	C	F	C	C
57	Sunset Hills Rd	2	40	17	3.3	0%	0.00	D	D	C	D
16	Fairfax Drive	3	35	12	7.3	100%	3.00	D	F	C	C
51	M St	4	30	7	9.1	0%	0.00	D	F	D	E
25	M St	4	30	11	3.7	0%	0.00	E	D	C	D
23	M St	4	30	8	5.6	0%	0.00	E	E	C	E
30	M St	4	30	7	14.5	0%	0.00	F	F	F	E
31	M St	4	30	4	18.0	0%	0.00	F	F	F	F
% Exact Match To Video								100%	26%	69%	37%
% Within 1 LOS of Video								100%	46%	94%	89%

CHAPTER 6

Transit LOS Model

6.1 Model Development

The Transit Capacity and Quality of Service Manual (TCQSM) provides a family of LOS models for dealing with several dimensions of transit service at different levels of geographic aggregation. The TCQSM is oriented to the entire service area, the entire route, or the bus stop. It was necessary to extract a subset of these quality-of-service measures that were most appropriate for a single urban street. The urban street is at a level of aggregation that is greater than the bus stop level and incorporates multiple routes using the street, but it covers just the portion of the routes that actually use the street. Thus a different geographic focus was necessary in the development of the Urban Street transit level of service model.

Transit riders were surveyed on portions of routes using a specific urban street to determine what factors most significantly influenced their perceived quality of service. It was quickly discovered that passengers were basing their LOS ratings on their entire trip experience up to that point and not just the portion of their trip on a specific urban street. In addition, an on-board survey can survey only those that eventually chose to ride transit; it cannot take into account the opinions of those who chose not to ride that bus or selected a different route. Consequently, the surveys were used to identify the key factors influencing perceptions of quality of service, but LOS models were not fitted to the on-board survey levels of service.

An alternative source of data on traveler preferences was necessary to construct an urban street level of service model for transit. The working hypothesis of the research team was that "people vote with their feet." When confronted with a choice, people will pick the service that gives them more of what they value, in our case, quality of service. Thus, standard models of transit mode choice were consulted to identify the relationships between various service characteristics and the likely proportional increase in ridership.

LOS E was set for a hypothetical, base transit service on an urban street. A mode choice model would then be used to compare the ridership for the actual transit service to that for the hypothetical base case. An increase in ridership over the hypothetical base case would be interpreted as an indication of a preference for the actual service over the base case. The actual service would be assigned a level of service superior to E. Similarly, lesser ridership would be interpreted as an indication of poorer quality of service and would be assigned a level of service inferior to E.

The application of mode choice models at the urban street level was considered impractical, so mode choice models were replaced with elasticities derived from typical mode choice models. The elasticities predict the percent increase in ridership as a function of percent change in the transit service characteristics.

Selection of Explanatory Variables for LOS

The Phase 1 surveys asked passengers to rate their satisfaction with 17 specific aspects of their trip. A multiple linear regression model was developed that related individual factor ratings to the overall satisfaction rating. The factors that added significance to the model were

- Close to home rating;
- Close to destination rating;
- Frequency rating;
- Reliability rating;
- Driver friendliness rating;
- Seat availability rating; and
- Travel time rating.

Of these factors, "close to home" and "close to destination" relate to getting to the stop, "frequency" and "reliability" relate to waiting at the stop, and "driver friendliness," "seat availability," and "travel time" relate to the ride on the bus.

Other considerations also had to be taken into account during this factor selection process:

1. The factors included in the model should be under the control of either the transit operator or the roadway owner;
2. To the extent possible and warranted, the factors as a whole should reflect the influence of other modes on transit quality of service;
3. The factors should be readily measurable in the field;
4. The factors should reflect conditions existing within the urban street right-of-way; and
5. The factors should have a documented impact on some aspect of customer satisfaction.

Based on these criteria, "driver friendliness" was dropped from consideration. Although partially under the control of the transit operator, this factor can only be measured through a customer satisfaction survey, which we felt made it impractical to include. In addition, we are not aware of any research relating different levels of driver friendliness to some measurable aspect of satisfaction (for example, increased ridership).

The factors "close to home" and "close to destination" generated considerable discussion among the project team. Walking distance to the stop depends on a number of factors beyond the urban street right-of-way, including land use patterns, street connectivity, transit route structure, stop locations, and sidewalk provision on connecting streets, which would tend to suggest not including these factors. At the same time, there are known relationships that describe how bus patronage declines the farther one has to walk to a stop.

One potential surrogate measure identified through initial statistical modeling is "number of stops per mile"—the more stops per mile, the shorter the distance passengers may have to walk to get to a stop once they reach the street with transit service. However, there are two potential difficulties with this measure. First, the more stops per mile, the slower the bus travel time. Travel time is already identified as a potential factor, so adding stops per mile to the model would be redundant. Second, long stop spacing may or may not be inconvenient to passengers, depending on how convenient the stops are to where passengers actually want to go. Without knowing something about adjacent land development patterns (which takes the analyst beyond the urban street right-of-way), it is hard to make a judgment about the impact of stop spacing on customer access.

Another potential surrogate measure would be the distance of the bus stop from the nearest intersection. This is something that may be influenced by the auto mode—for example, traffic engineers frequently do not want far-side bus stops located adjacent to intersections, in situations where buses must stop in the travel lane, because of the potential for cars to stop behind the bus and block the intersection. Moving the stop farther from the intersection increases walking distances for passengers arriving from three of the four directions at the intersection, which can be related to walking time. On the other hand, near-side/far-side stop location trade-offs can be evaluated through changes in travel speed, using methodologies found in the TCQSM.

A third potential surrogate, and the one recommended by the project team, is pedestrian LOS. Pedestrian LOS relates to the ease of access to and from destinations along the urban street, the quality of pedestrian facilities serving the bus stop, and the difficulty of crossing the street. It will be a part of the multimodal urban street LOS methodology; therefore, no additional data collection will be required. It is a measure of the impact of another mode on the transit mode and can be impacted by roadway agency actions. In short, it meets all of the criteria set out above.

The TCQSM provides an areawide measure, "service coverage," that addresses the "close to home" and "close to destination" factors. This measure accounts for land use patterns, street connectivity, and street-crossing difficulty, at the cost of requiring more data than is desirable for an urban street analysis.

The four remaining candidate factors are travel time, reliability, seat availability, and frequency. All are impacted by conditions on the urban street, or by transit or roadway agency actions. All are related to TCQSM measures, which is important from a consistency standpoint. The first three factors can be related to travel time, which addresses a panel request to consider travel speed in the transit LOS model. The key remaining question is: Do relationships exist between passenger satisfaction and different values of these factors?

The answer to this question appears to be "yes." Considerable research has been conducted on traveler ridership responses to changes in service frequency and travel time. (Both *TCRP Report 95: Traveler Response to System Changes,* and the Victoria Transport Policy Institute's *Online TDM Encyclopedia* provide extensive summaries of the literature pertaining to ridership responses to transit system changes.) For example, as bus headways decrease from 60 minutes to 30 minutes, from 30 minutes to 15 minutes, and so on, ridership increases, although in an ever-decreasing proportion to the amount of added service. All other things being equal, the relative amount of ridership one would expect at a given headway, compared to a 60-minute headway, is reflective of the difference in customer satisfaction between the two headways.

There is comparatively little research on the impacts of reliability and crowding on ridership. However, reliability can be converted to an "excess wait time"—the average additional amount of time one would wait for a bus as a result of non-uniform headways. The excess wait time can, in turn, be converted into a perceived wait time, with an impact greater than the actual wait time [**98**]. Time spent standing or even seated in a crowded transit vehicle is also perceived by passengers as being more onerous than the actual travel time (See, for example, Balcombe [**99**]). Thus, the level of crowding on a bus can be used to convert an actual in-vehicle travel time to a perceived in-vehicle travel time. Furthermore, variable headways result in uneven loadings on buses, with the result that late buses are more crowded than would be suggested by an average peak-hour or peak-15-minute load. Finally, research exists to document how certain kinds of stop amenities can help reduce the perceived waiting time at bus stops.

Therefore, the recommended factors to include in the transit LOS model are the following:

- Service frequency (headways);
- Travel time (speed);
- Crowding;
- Reliability (headway variability);
- Presence of stop amenities documented to reduce perceived wait time; and
- Pedestrian LOS.

Proposed General Model Form for Transit LOS

The proposed general form for the transit LOS model is a linear combination of the quality of service accessing the bus stop on foot and the quality of service involved in waiting for and riding the bus. It is similar to many transit mode choice models incorporating the factors of accessibility, wait time, and travel time to predict the probability of choosing transit. This model form varies slightly from traditional mode choice models in that it blends wait time and travel time into a single factor before adding the result to the accessibility. Only pedestrian accessibility is considered (as opposed to auto accessibility) because this model is designed for application in an urban street environment where park and ride is less likely a phenomenon.

$$\text{Transit LOS} = a1 * \text{Pedestrian Access} + a2 * \text{Transit Wait/Ride} \qquad \text{(Eq. 20)}$$

Where:

a1, a2 = calibration parameters
Pedestrian Access Score = A measure of the pedestrian level of service for the street.
Transit Wait/Ride Score = A measure of the quality of transit ride and waiting time.

The quality of the pedestrian access can be conveniently obtained by employing the pedestrian level of service score for the street.

The quality of the transit wait/ride experience would be measured based on the average wait time for a bus and the perceived travel time on the bus.

The ratio of transit patronage for the actual wait time divided by the patronage for a base wait time gives an indication of the perceived quality of the service provided relevant to the wait time.

The ratio of transit patronage for the perceived travel time rate (minutes per mile, the inverse of the speed) divided by the patronage for a base travel time rate gives an indication of the perceived quality of the service provided relevant to the travel time rate of service.

The patronage ratios are estimated based on patronage elasticities obtained from various research, as explained in the following sections.

Elasticity Concept

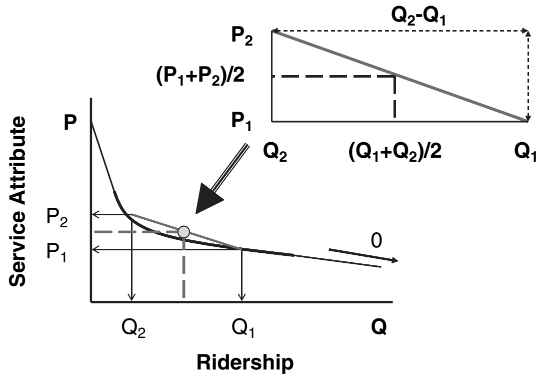
For practical purposes it is not feasible to apply full mode choice models to an isolated urban street (because the mode choice models are designed to consider the entire trip while the street is limited to portions of the trip). Elasticities were adopted instead since they can be used to predict changes in ridership without having to consider the full length of the trip.

A basic, hypothetical transit service for the urban street is assumed which would provide LOS E as far as transit patrons are concerned. The difference between the actual service and the hypothetical service is converted into an estimated percentage change in ridership to determine by how much the actual service LOS exceeds (or falls below) LOS E.

The two key components of the *TransitWaitRideScore* are the headway factor and the perceived travel time factor. These in turn, are related to documented traveler responses to changes in headway and changes in travel time. These responses are quantified in terms of elasticities.

Transit elasticities reflect the percent change in transit ridership resulting from a 1% change in an attribute of the service (e.g., fare, frequency, travel time, service hours, etc.). The relationship between demand and service attribute need not be linear. This is the case with service frequency: doubling the frequency from one bus to two buses an hour on a route has a much greater percentage impact on ridership than doubling the frequency from six buses to twelve buses an hour. Thus, the value of elasticity, *E,* may be different depending on where one starts from and where one ends up. *TCRP Report 95,* the source of many of the elasticity values used for the transit model, uses the concept of *mid-point arc elasticity* to approximate this relationship, based on average before-and-after values of the two variables, ridership and service attribute [**100**]. These relationships are illustrated in Exhibit 82 and expressed mathematically in the equation below.

Exhibit 82. Mid-Point Arc Elasticity.



$$E = \frac{\Delta Q}{(Q_1+Q_2)/2} \div \frac{\Delta P}{(P_1+P_2)/2} = \frac{\Delta Q(P_1+P_2)}{\Delta P(Q_1+Q_2)} = \frac{(Q_2-Q_1)(P_1+P_2)}{(Q_1+Q_2)(P_2-P_1)} \quad \text{(Eq. 21)}$$

Where

E = mid-point arc elasticity;

P = the before (P_1) and after (P_2) prices (e.g., fare, headway, travel time); and

Q = the before (Q_1) and after (Q_2) ridership demand.

Elasticity is relative—the actual ridership of a route is determined by many factors, including the type and density of adjacent land uses, the demographic characteristics of persons living near the route (e.g., age and vehicle ownership), and the ease of access to bus stops. However, given no changes in these external factors, one can estimate the change in a route's ridership resulting from a change in a single service attribute under the control of a transit or roadway agency. Whether the resulting change in ridership is from 100 to 150 riders, or from 1,000 to 1,500 riders makes no difference—one can still estimate how much more attractive (satisfactory) one level of a particular service attribute to passengers is compared to another.

Bus Frequency Elasticity

Elasticities related to how often bus service is provided can be expressed as frequency elasticities (using positive numbers—increased frequencies result in increased ridership) or as headway elasticities (using negative numbers—decreased headways result in increased ridership). Trends identified in *TCRP Report 95* suggest that frequency elasticities can be +1.0 or greater, in situations where the original service was very infrequent (60-minute headways or longer), that is, doubling the frequency may more than double the ridership in those situations. With more frequent service as a starting point, typical frequency elasticities are in the +0.3 to +0.5 range, dropping to as low as +0.2 with very frequent service (i.e., service every 10 minutes or better).

The recommended transit LOS model uses the following frequency elasticity values, based on typical values reported in *TCRP Report 95*: +1.0 for 1–2 buses/hour, +0.5 for 2–4 buses/hour, +0.3 for 4–6 buses/hour, and +0.2 for 6 or more buses/hour. Solving for Q_2 in Equation 1, one can estimate future ridership demand based on a given starting demand and an assumed elasticity, as shown Equation 22 below.

$$Q_2 = \frac{\left((E-1)P_1Q_1\right)-\left((E+1)P_2Q_1\right)}{\left((E-1)P_2\right)-\left((E+1)P_1\right)} \quad \text{(Eq. 22)}$$

Thus, with an elasticity of +1.0, a route with a ridership of 100 passengers at 60-minute headways (P_1 = 1 bus/hour) would be expected on average to have a ridership of 133 passengers if headways improved to 45 minutes (P_2 = 1.33 bus/hour), and a ridership of 200 passengers if headways improved to 30 minutes. With the decreased response to frequency changes assumed to begin at 30-minute headways, ridership would increase to 244 passengers at 20-minute headways (E = +0.5, Q_1 = 200 passengers, P_1 = 2 buses/hour, and P_2 = 3 buses/hour), 280 passengers at 15-minute headways, 316 passengers at 10-minute headways, and 379 passengers at 5-minute headways. For any given frequency or headway, one can estimate the ridership relative to a 60-minute headway and, thus, the relative attractiveness of the service. In this example, 10-minute headways produce 3.16 times the number of passengers compared to 60-minute headways, all other things being equal; therefore, the value of f_h that would be used for 10-minute headways would be 3.16.

If local data were available, local elasticities could be substituted for the typical national values used in the model.

Travel Time Elasticity

A review of transit travel time elasticities in the literature, conducted by TCRP Project A-23A (Cost and Effectiveness of Selected Bus Rapid Transit Components), found a typical range of -0.3 to -0.5 (that is, for every 1% decrease in travel time, ridership increases by approximately 0.3 to 0.5%) [**101**]. The *TCRP Report 95* chapter on Bus Rapid Transit, where travel time elasticities will probably be covered, has not yet been published.

Assuming some baseline travel time that passengers would be satisfied with, additional travel time above this baseline value would be less satisfactory, while a reduction in travel time would be more satisfactory. The relative satisfaction of passengers associated with a given travel time can be expressed in terms of the ridership expected at the actual travel time, relative to the ridership that would occur at the baseline travel time. For example, a route with an average passenger travel time of 25 minutes would be expected to have 10% higher ridership than a route with an average passenger travel time of 30 minutes, all other things being equal, assuming an elasticity of -0.5. (This value is calculated using Equation 2, rather than by taking a 16.7% difference in travel times and multiplying by 0.5). Therefore, if a 30-minute travel time was set as the baseline, the value of f_{ptt} would be 1.10 for 25-minute travel times, assuming for the moment no other influences on perceived travel time.

Because urban street LOS focuses on the quality of urban street segments, rather than the bus trip as a whole, the alternative transit LOS model works with travel time rates (e.g., 6 minutes per mile) instead of travel times (e.g., 30 minutes) or travel speeds (e.g., 10 mph). Travel time rates are the inverse of speeds and, over a given distance, change at the same rate that travel times do. For example, if a bus' travel time to cover 2 miles decreases from 12 to 11 minutes, the travel time decreases by 8.3% and so does the travel time rate (from 6 minutes per mile to 5.5 minutes per mile). Because the rate of change is the same, travel time elasticities should also apply to changes in travel time rates.

The f_{ptt} factor serves to increase or decrease LOS when transit service is particularly fast or slow, compared with some neutral, baseline value. The f_{ptt} and f_h factors, in combination, produce a *TransitWaitRideScore* that represents the percent increase in ridership for a particular headway and perceived travel time rate, compared with a baseline of 60-minute service at a baseline speed.

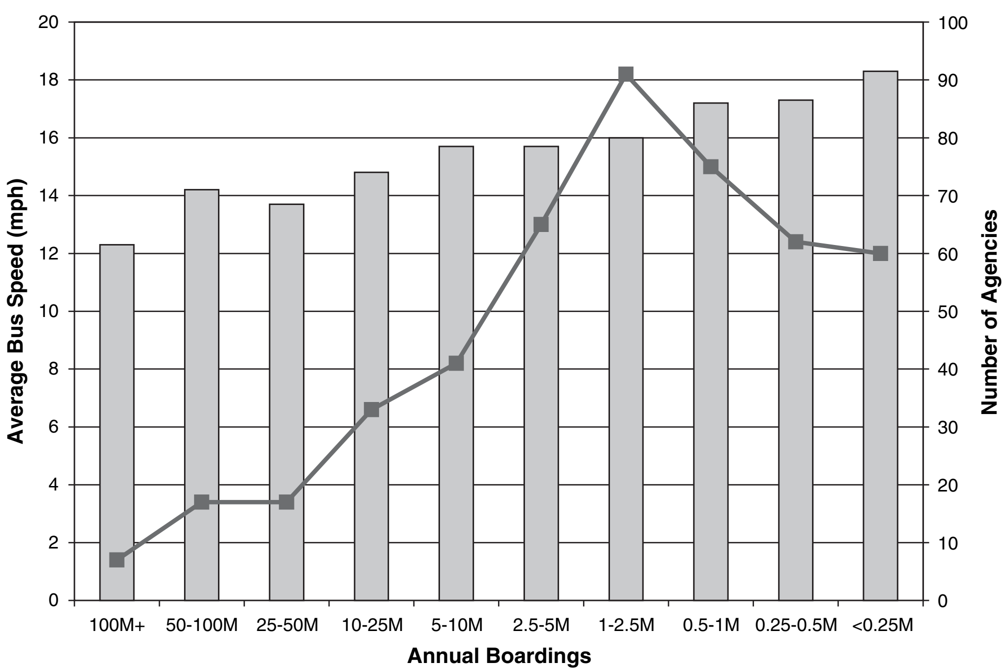
Selection of a Baseline Travel Time Rate

Originally 6 minutes/mile (10 mph) was proposed as a preliminary value for the baseline travel time rate, based on LOS ranges given in *TCRP Report 26* [**102**]. Testing of the preliminary model using real-world data for the entire TriMet bus system in Portland, Oregon, found that the travel time rate of 6 minutes/mile resulted in LOS ratings for Portland that were too high (62-69% of all street segments ended up as LOS A).

The National Transit Database (NTD) can be used to calculate a systemwide average bus speed, in terms of revenue miles operated divided by revenue hours operated. "Revenue service" consists of the time a bus is in passenger operation—it does not include travel to or from the bus garage, but does include driver layover time at the end of the route. To eliminate the effect of layover time on average speed, we assumed that layover time was 10% of total revenue hours, which is a typical transit industry standard, although local contracts with the bus drivers' union may specify a different value.

For all bus systems reporting to the NTD, the median speed is 15.2 mph. As shown in Exhibit 83, average speed is a function of city size: the larger the city, the lower the speed. For the seven largest bus operators (serving 100 million or more annual boardings), the mean speed was 12.3 mph; for the 60 smallest bus operators reporting to the NTD (10 or more buses in service and fewer than 250,000 annual boardings), the mean speed was 18.3 mph. The 33 bus operators in the 10 to 25 million boardings category (Montgomery

Exhibit 83. Average System Bus Speed by Number of Annual Boardings.



County, Maryland, and Cincinnati, Ohio are toward the top of this group) had a mean speed of 14.8 mph, while the 91 bus operators in the 1 to 2.5 million boardings category (Appleton, Wisconsin, and Pueblo, Colorado are toward the bottom of this group) had a mean speed of 16.0 mph. In total, 247 bus agencies out of 468 reporting (53%) are represented by groups with mean speeds within 1 mph of the median speed of 15.2 mph; thus, this median value is representative of most U.S. bus agencies.

When a baseline travel time rate of 4 minutes/mile (15 mph) was tested against the Portland data, a much better distribution of LOS grades was obtained, with only 30 to 39% of route segments receiving LOS A grades, depending on whether route-average or segment-specific speeds were used in the calculation.

However, a baseline travel time rate of 4 minutes/mile, when applied to the San Francisco surveys, results in LOS grades that were too low relative to the frequency of service provided. This suggests that a different baseline travel time rate may be appropriate for dense urban areas such as San Francisco or downtown Washington, DC. Further testing of the speed elasticity used in the model would also be appropriate.

Reliability

One way that the TCQSM measures transit reliability is through the *coefficient of variation of headway deviations*—the standard deviation of headway deviations divided by the mean scheduled headway. (A headway deviation of a given bus is the actual headway minus the scheduled headway. When buses arrive exactly on schedule every time, $cv_h = 0$; when two buses consistently arrive together, $cv_h = 1$.)

Some believe that a better reflection of headway reliability from a passenger point-of-view is given by *excess wait time* (e.g., Furth and Miller (previously cited) and Transport for London's transit performance standards), which is the average additional time a passenger must wait for a bus to arrive because of non-uniform headways. When passengers arrive randomly at a stop—the case when service is relatively frequent (the TCQSM suggests this occurs at headways of 10 to 12 minutes or less)—the average passenger will wait half a headway for a bus to arrive. When a bus is late, passengers will wait longer than half a headway on average. The difference in these two times is the excess wait time.

For random passenger arrivals, excess wait time is calculated as half the scheduled headway multiplied by the square of the coefficient of variation of headways (or headway deviations) [**103**, **104**]. For non-random arrivals (i.e., for longer headways, when passengers would be expected to be familiar with the schedule and arrive a few minutes before the scheduled departure time), excess wait time is the average number of minutes that buses are behind schedule. Buses more than a minute early can be treated as being one headway behind schedule, because passengers arriving near the scheduled departure time would have to wait for the next bus. Excess wait time adds to a passenger's overall wait time; it also affects a passenger's perceived wait time. A common value in the literature is that passengers perceive or value wait time approximately twice as much as in-vehicle time; Furth and Muller suggest a value of 1.5 and suggest accounting for "potential wait time," an allowance a rider makes to show up earlier for service known to be unreliable, with a value of 0.75 of in-vehicle time [**98**].

Excess wait time makes a passenger's trip take longer than intended (i.e., the perceived speed or travel time rate for the trip is slower). However, the effect of excess wait time on the travel time rate varies depending on the length of the trip: a 2-minute excess wait has a bigger proportional effect on a 10-minute trip than a 2-minute wait for a 20- or 30-minute trip. The difficulty is in determining what an appropriate trip length should be.

The recommended solution is to compare the excess wait time with the average trip time. The NTD provides information on weekday boardings and passenger miles by mode each year for most transit systems; an average trip length (miles/boarding) can be computed from these two variables. (This calculation assumes that trip lengths are consistent throughout the day, which may or may not be the case. Passenger miles are only available as daily values. Although the NTD allows agencies to report boardings in smaller time increments than a day (e.g., AM peak, midday, etc.), most choose not to.)

Dividing the excess wait time (minutes) by the computed average trip length (miles) provides the average effect on the overall travel time rate (minutes/mile), which can then be converted to a perceived travel time rate. For example, if the analysis were being performed in Portland, the average weekday passenger miles in 2003 were 765,100, while the average weekday boardings were 214,158, resulting in an average trip length of 3.57 miles. If the average excess wait time was 2 minutes, the additional travel time rate would be $(2 / 3.57) = 0.56$ minutes/mile. The *perceived* additional travel time rate could be up to twice this value, or 1.12 minutes/mile.

Effect of Stop Amenities on Perceived Waiting Time

Research presented in *TRL Report 593* suggests that certain stop amenities, including shelters, lighting, and seating, can reduce perceived journey time by providing a more comfortable waiting environment. Exhibit 84 presents these values, converted from pence to in-vehicle time, using an in-vehicle time value of 4.2 pence per minute.

Some authors have suggested that real-time displays at bus stops showing the number of minutes until the next bus arrival

Exhibit 84. In-Vehicle Time Value of Stop Amenities.

Amenity	In-Vehicle Time Value (min)
Shelter with roof and end panel	1.3
Shelter with roof	1.1
Lighting at bus stop	0.7
Molded seats	0.8
Flip seats	0.5
Bench seats	0.2

SOURCE: Calculated from Steer Davies Gleave, *Bus passenger preferences. For London Transport buses.* (1996) in Balcombe, R. (editor), [**105**].

should reduce, if not eliminate, the perceived travel time penalty. (In other words, perceived excess wait time would be the same as actual excess wait time when real-time bus-arrival information is provided.) Although this seems to be a reasonable hypothesis, to date, the project team has not seen any literature documenting such an effect.

Crowding

Perceived Travel Time Effects

In the same way that passengers perceive or value wait time more than in-vehicle time, passengers also perceive or value time spent in crowded conditions more than time spent in uncrowded conditions. Exhibit 85 presents values of train crowding used in Great Britain.

To demonstrate how the Exhibit 85 information could be applied, consider a situation where a train is operating with a passenger load that is 120% of its seating capacity (i.e., a load factor of 1.20). In the absence of crowding, rail commuters value in-vehicle time at 7.2 pence/minute. At a load factor of 1.20, seated commuters experience a penalty of 1.6 pence/minute due to the more crowded conditions, while standing commuters experience a penalty of 7.5 pence/minute (i.e., standees perceive their time spent standing as being more than twice as onerous as being seated in an uncrowded carriage). The weighted average penalty for all passengers in the

Exhibit 85. British Crowding Penalties for Rail Passengers.

	Crowding Penalty (pence/min)	
Load Factor (p/seat)	Seated Passengers	Standing Passengers
≤ 0.80	0.0	--
0.90	0.4	--
1.00	0.8	6.5
1.10	1.2	7.0
1.20	1.6	7.5
1.30	2.0	8.0
1.40	2.4	8.5
1.50	--	9.0
1.60	--	9.5

NOTE: The baseline value of in-vehicle time for rail passengers is 7.2 pence/minute, in 2000 prices. Intermediate values are obtained through linear interpolation. The baseline value of in-vehicle time for bus passengers is 4.2 pence/minute; no corresponding crowding penalties are available.
SOURCE: Derived from Balcombe [**106**].

train would be 2.58 pence/minute, corresponding to a value of time 36% higher than in uncrowded conditions. This value-of-time factor, 1.36, corresponds to factor a_1 in the perceived travel time rate equation. In application, the transit LOS model would provide a lookup table based on a similar calculation using bus passenger value-of-time to directly provide a_1. Section 6.10 provides an example of such a lookup table.

No corresponding British values exist for bus crowding penalties and no American work was found that could be used to compare U.S. rail crowding perceptions to U.K. perceptions. Additional research would be needed to establish U.S. crowding penalty values. In the absence of other data, the recommended transit model uses a combination of U.K. bus value-of-time data and rail crowding penalties.

Load Variability Effects

Unreliable operations tend to result in higher levels of crowding on buses that are running late, because these buses pick up not only their own passengers, but passengers who have arrived early for the following bus. For existing-condition analyses, this crowding can be measured directly. For future-condition analyses, for frequent service (i.e., headways approximately 10 minutes or less), this additional crowding can be estimated as the mean load multiplied by $(1 + cv_h)$ (Derived from the TCQSM, Part 4, Appendix E, Equations 4-22 and 4-23). At long headways, a late bus will pick up its normal load, because passengers will have timed their arrival at the bus stop to the expected departure time (Furth and Miller, previously cited). There is also an intermediate range of headways with a mix of randomly and non-randomly arriving passengers [**107**]. This late-bus load can be used in the perceived travel time calculation described in the previous section, thus incorporating the effect of unreliable service's crowding into the LOS measure.

The literature review uncovered no information directly relating overcrowding and/or reliability to transit demand. In the United States, the San Francisco County Transportation Authority appears to be the only agency to have documented a test of reliability and crowding factors for use in a travel demand model. The tested values were based on a stated-preference telephone survey, but were not incorporated in the final model because the predicted number of boardings did not reasonably match the observed number of boardings [**108**].

6.2 Recommended Transit LOS Model

The recommended transit LOS model predicts the average quality of service rating that transit riders would give the bus service on an urban street. The model is as follows:

$$\text{Transit LOS Score} = 6.0 - 1.50 * \text{TransitWaitRideScore} + 0.15 * \text{PedLOS} \quad \text{(Eq. 23)}$$

Where

PedLOS = The pedestrian LOS numerical value for the facility (A=1, F=6).

TransitWaitRideScore = The transit ride and waiting time score, a function of the average headway between buses and the perceived travel time via bus.

The computed transit LOS score is converted to a letter LOS grade using the equivalencies given in Exhibit 86. These are the same thresholds as used for auto.

Estimation of the Pedestrian LOS

The pedestrian LOS for the urban street is estimated using the pedestrian LOS model described in a later chapter.

Estimation of the Transit Wait Ride Score

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

$$\text{TransitWaitRideScore} = f_h * f_{ptt} \quad \text{(Eq. 24)}$$

Where

f_h = headway factor = the multiplicative change in ridership expected on a route at a headway *h,* relative to the ridership at 60-minute headways;

f_{ptt} = perceived travel time factor = the multiplicative change in ridership expected at a perceived travel time rate *PTTR,* relative to the ridership expected at a baseline travel time rate.

The baseline travel time rate is 4 minutes/mile except for central business districts of metropolitan areas with over 5 million population, in which case it is 6 min/mile.

Exhibit 87 provides f_h values for typical bus headways.

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

$$F_{PTTR} = \frac{[(e-1)BTTR-(e+1)TTR]}{[(e-1)TTR-(e+1)BTTR]} \quad \text{(Eq. 25)}$$

Exhibit 86. Transit LOS Thresholds.

LOS	Numerical Score
A	≤ 2.00
B	>2.00 and ≤ 2.75
C	>2.75 and ≤ 3.50
D	>3.50 and ≤ 4.25
E	>4.25 and ≤ 5.00
F	> 5.00

Exhibit 87. Headway Factor Values.

Headway (min)	Frequency (bus/h)	f_h
60	1	1.00
45	1.33	1.33
40	1.5	1.50
30	2	2.00
20	3	2.44
15	4	2.80
12	5	2.99
10	6	3.16
7.5	8	3.37
6	10	3.58
5	12	3.79

NOTE: The following frequency elasticities are assumed: +1.0 for 1-2 buses/hour, +0.5 for 2-4 buses/hour, +0.3 for 4-6 buses/hour, and +0.2 for 6 or more buses/hour. Elasticities derived from data reported in *TCRP Report 95,* Chapter 9.

Where

F(PTTR) = Perceived Travel Time Factor

PTTR = Perceived Travel Time Rate (min/mi)

BTTR = Base Travel Time Rate (min/mi). Use 6 minutes per mile for the main central business district of metropolitan areas with population greater than or equal to 5 million. Use 4 minutes per mile for all other areas.

e = ridership elasticity with respect to changes in the travel time rate. The suggested default value is –0.40, but local values may be substituted.

Exhibit 88 below illustrates the application of this equation for selected perceived travel time rates and a selected elasticity.

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

Exhibit 88. Example Perceived Travel Time Factors (F(PTTR)).

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

Notes:

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

$$PTTR = a_1 * IVTTR + a_2 * EWTR - ATR \quad \text{(Eq. 26)}$$

Where
PTTR = perceived travel time rate.
IVTTR = actual in-vehicle travel time rate, in minutes per mile.
EWTR = excess wait time rate due to late arrivals = excess wait time (minutes) / average trip length (miles).
a_1 = passenger load weighting factor (a function of the average load on buses in the analysis segment during the peak 15 minutes).
a_2 = 2 = wait time factor, converting actual wait times into perceived wait times.
ATR = amenity time rate = perceived travel time rate reduction due to the provision of certain bus stop amenities = in-vehicle travel time value of stop amenities (minutes) / average trip length (miles).

Exhibit 89. Passenger Load Weighting Factor (a_1).

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

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

In-Vehicle Travel Time Rate

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

$$IVTTR = \frac{60}{Speed} \quad \text{(Eq. 27)}$$

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

When field measurement of mean bus speed is not feasible, the mean schedule speed can be used. Identify two schedule points on the published schedule for the bus route(s). Measure the distance covered by the bus route(s) between the two points. Divide the measured distance by the scheduled travel time between the two schedule points. The bus speed estimation procedure given in Chapter 27 (Transit) may be used to estimate future bus speeds.

The in-vehicle travel time rate is multiplied by a passenger load weighting factor (a_1) to account for the increased discomfort when buses are crowded. Values of the passenger load weighting factor (a_1) are given in Exhibit 89.

Excess Wait Time Rate

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

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

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

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

Amenity Time Rate

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

$$ATR = \frac{1.3 * Shelter + 0.2 * Bench}{ATL} \quad \text{(Eq. 28)}$$

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

Notes:
1. Shelters with benches are counted twice—once as shelters, once as benches.
2. Coefficients adapted from Steer Davies Gleave, *Bus passenger preferences. For London Transport buses.* (1996) in Balcombe, R. (editor) [**109**].

6.3 Performance of Transit LOS Model

Exhibit 90 compares the ability of the existing TCQSM LOS models and the proposed transit LOS model to predict the mean LOS response for each bus route obtained from the field surveys.

None of the models reproduce the mean levels of service reported by passengers in the on-board surveys very well. Both the FDOT LOS and proposed LOS model match the passenger surveys about 21% of the time. Although a better match might have been desirable, the on-board survey results indicate a high degree of acceptance for a wide range of conditions. It is thought that passengers not satisfied with the service are less likely to ride the buses and thus were undersampled in the survey. Consequently, it was considered acceptable that the proposed transit LOS model should predict poorer levels of service than obtained in the on-board surveys.

The scope of the TCQSM LOS model is quite a bit different than the urban street. The TCQSM is designed to represent the entire trip, while this research is limited to transit service on a given street. Also, the TCQSM provides six different letter grade levels of service, depending on the geographic scope and aggregation of the analysis. Only the worst result is shown in the table.

Both the FDOT LOS model and the proposed transit LOS model predict a range of LOS A to E for the transit routes surveyed. All three LOS models, FDOT, TCQSM, and the proposed transit LOS model, tend to agree that WMATA Route 2B and AC Transit Route 218 are LOS D/E, which passengers rated as LOS A.

Exhibit 90. Evaluation of Proposed Transit Model and TCQSM against Field Survey Results.

Operator	Rte	Freq. (bus/h)	Spd (mph)	OTP %	Shelter (%)	Bench (%)	LF (p/seat)	Ped LOS	CBD	Survey LOS	FDOT LOS	TCQSM LOS	Model LOS
TriMet	14	8	11.8	75%	34%	47%	0.55	C	No	A	A	C	A
TriMet	44	4	14.8	76%	30%	41%	0.83	C	No	A	B	D	A
AC Transit	72R	5	15.7	66%	74%	75%	1.10	D	No	A	B	D	B
AC Transit	72	4	12.1	53%	39%	46%	1.10	D	No	A	B	D	B
WMATA	38B	4	10.1	46%	29%	26%	0.38	D	No	A	C	D	B
WMATA	2B	2	14.0	67%	13%	15%	1.10	D	No	A	E	D	D
AC Transit	218	1	15.1	72%	11%	15%	1.10	C	No	A	E	E	E
AC Transit	51	8	11.8	54%	28%	51%	1.10	D	No	B	A	C	A
SF Muni	14	10	9.2	57%	54%	56%	1.30	E	Yes	B	A	C	C
SF Muni	30	7	7.4	59%	44%	44%	1.30	E	Yes	B	A	C	D
SF Muni	1	20	8.8	63%	44%	44%	1.30	C	Yes	B	A	C	A
SF Muni	38	8	9.8	59%	68%	69%	1.30	F	Yes	B	B	C	D
SF Muni	38L	9	12.1	48%	84%	86%	1.10	F	No	B	B	C	A
Broward	18	4	13.6	65%	23%	75%	1.10	E	No	B	C	D	B
% Exact Match										100%	21%	0%	21%
% Within 1 LOS										100%	86%	43%	71%

Notes:
1. OTP = on time performance with 5 minutes late considered on-time.
2. LF = load factor
3. Shelter = percent of bus stops with shelters.
4. Bench = percent of bus stops with benches.
5. Survey = the mean level of service reported in the field survey.
6. FDOT = Florida Quality/Level of Service Handbook method.
7. TCQSM = Transit Capacity and Quality of Service Manual. The TCQSM does not produce a single letter grade LOS for transit routes. The letter grade reported here is an average, a grade point average (GPA) of the numerous LOS ratings that the TCQSM reports for any given transit route.
8. Model LOS = the letter grade predicted by the recommended transit LOS model.

CHAPTER 7

Bicycle LOS Model

7.1 Development

Two basic forms were considered for the bicycle LOS for arterials model. The first was an aggregate model using the outputs from existing segment and intersection LOS models to determine the arterial LOS. The other was an agglomerate model considering the independent characteristics of the roadway environment to calculate an arterial LOS for bicyclists directly. Both forms were preliminarily evaluated during model development.

The aggregate model was chosen for refinement for several reasons. The stepwise approach to an aggregate model is useful because it allows the practitioner to address concerns at individual intersections or along specific segments. The aggregate model also retains all the terms found both intuitively and mathematically to be significant to bicyclists riding along a roadway. The agglomerate model would not retain all the terms as significant. Consequently, we focused on the aggregate model in model development efforts.

We considered various functional techniques for model development, including linear regression and ordered probit. We performed linear regression modeling because it is more intuitive than probit modeling in practice and non-modelers better understand the sensitivity of the regression model. These reasons are particularly important in that these models are most frequently used: the development or analysis of specific design options or in the development of bicycle facility community master plans with presentations to interested citizens and public officials. To ensure the validity of the results of the linear regression modeling results, we evaluated the ordered probit model form as well. The results of both the linear regression and ordered probit modeling efforts are described below.

Before starting correlations analysis and modeling, we created two data subsets from the overall dataset. The total dataset was sorted by city and LOS grade responses. A random sampling of 20% of the data representing each city and LOS grade response was taken from the overall dataset for model validation. The balance of the data, 80% of the total dataset, was used for model development.

SPSS 14.0 was used to conduct Pearson correlation analysis on the extensive array of geometric and operational variables. Subsequently, we selected the following relevant variables for additional testing:

- Segment LOS—The bicycle LOS for roadway segments (see below).
- Intersection LOS—The bicycle LOS for signalized intersections (see below).
- Conflicts per mile—The total conflicts per mile represent the motor vehicle conflicts resulting from motorists turning across the bicycle facility at unsignalized locations.
- Size of the city in which the data collection took place—The Metropolitan Statistical Area (MSA) population was used to represent the size of each city.

At the panel's request, the MSA variable was dropped from further consideration. Other variables were dropped from further consideration because of their poor correlation with the dependent variable or because of their colinearity with more strongly correlated variables. After testing numerous combinations of variables and variable transformations, we determined the aggregate model using two constituent sub-models would be the most theoretically valid.

7.2 Recommended Bicycle LOS Model

The recommended bicycle LOS model is a weighted combination of the bicyclists' experiences at intersections and on street segments in between the intersections. Two models of the same form were evaluated, but with different parameters:

Bicycle LOS Model 1

$$\text{Bicycle LOS \#1} = 0.160*(\text{ABSeg}) + 0.011*(\exp(\text{ABInt})) + 0.035*(\text{Cflt}) + 2.85 \quad \text{(Eq. 29)}$$

Bicycle LOS Model 2

$$\text{Bicycle LOS \#2} = 0.20*(\text{ABSeg}) + 0.03*(\exp(\text{ABInt})) + 0.05*(\text{Cflt}) + 1.40 \quad \text{(Eq. 30)}$$

Where

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

The output of either model is a numerical value, which must be translated to a LOS letter grade.

Exhibit 91 provides the numerical ranges that coincide with each LOS letter grade.

The first model provides a better fit with the numerical scores given by the video lab participants to the video clips. This model was derived based on a statistical fitting process to the video clip data. However, this first model does not predict LOS A or B for the video clips. Consequently the second model was developed.

The second model has an inferior numerical fit with the video lab data (measured in terms of squared error) but produces the full range, LOS A through F, for the video clips. The second model was derived from the first model by reducing the constant so that the second model would predict LOS A for video clips #328 and #330. The other parameters in the model were then manually adjusted until the second model could produce LOS F for one or more of video clips #314, 317, 323, and 324 (which were rated LOS F by the video lab participants).

Both models use the same bicycle segment and bicycle intersection submodels.

Bicycle Segment LOS

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

Exhibit 91. Bicycle LOS Numerical Equivalents.

LOS	Numerical Score
A	≤ 2.00
B	>2.00 and ≤ 2.75
C	>2.75 and ≤ 3.50
D	>3.50 and ≤ 4.25
E	>4.25 and ≤ 5.00
F	> 5.00

$$\text{BSeg} = 0.507 \ln(V/(4*\text{PHF}*L)) + 0.199\text{Fs}*(1 + 10.38\text{HV})^2 + 7.066(1/\text{PC})^2 - 0.005(\text{We})^2 + 0.760 \quad \text{(Eq. 31)}$$

Where

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

Bicycle Intersection LOS

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

$$\text{IntBLOS} = -0.2144\text{Wt} + 0.0153\,CD + 0.0066\,(\text{V}ol15/L) + 4.1324 \quad \text{(Eq. 32)}$$

Where

IntBLOS = perceived hazard of shared-roadway environment through the intersection
Wt = total width of outside through lane and bike lane (if present)
CD = crossing distance, the width of the side street (including auxiliary lanes and median)

Vol15 = volume of directional traffic during a 15-minute period

L = total number of through lanes on the approach to the intersection

7.3 Performance of Bicycle LOS Model on Video Clips

Exhibit 92 compares the ability of the existing HCM speed-based LOS model and the proposed bicycle LOS models against the mean LOS response for each video clip. The HCM matched the video clips 15% of the time. The proposed LOS models matched the clips between 27% and 46% of the time. The second model had the highest percentage match because it can predict LOS A and B. The first model is better at predicting the poorer levels of service (E and F) than the second model.

Exhibit 92. Evaluation of Proposed Bike Models and HCM against Video Lab Results.

Clip	Location	Outside Lane (ft)	Bike/Shldr Lane (ft)	Through Lanes	Divided (D/UD)	Pk Hr. Vol. (vph)	Heavy Veh (%)	Spd Lim (mph)	Pavement Rate (1-5)	% OSP	Sig. Int X-Dist (ft)	Unsig. Conf Per Mile	Video LOS	HCM LOS	Model #1 LOS	Model #2 LOS
328	N Village, Cypress/S Vill.(N)	12	4	1	U	79	0%	30	4.0	0%	0	5.5	A	B	C	A
330	N Village, S Vill./Cypress (S)	12	4	1	U	136	0%	30	4.0	0%	0	6.7	A	B	C	A
306	Alumni at Magnolia (N)	11	4	2	U	717	0%	30	4.0	0%	72	0.0	B	B	C	B
305	Collins at Alumni (W)	12	3.5	2	D	813	8%	30	3.5	0%	65	0.0	B	C	D	B
307	Alumni at Magnolia (N)	11	4	2	U	757	0%	30	4.0	0%	72	0.0	B	D	C	B
304	Collins Blvd at Alumni (E)	12	3.5	2	D	428	0%	30	3.5	0%	65	0.0	B	E	C	B
303	Fowler Ave at North	12	5	3	D	1211	0%	50	4.0	0%	0	26.4	C	B	D	C
319	Fletcher, North Palm (S)	12	5	2	D	2961	0%	45	4.0	0%	53	0.0	C	B	D	D
311	15th St at 7th Ave, (W)	12	8	1	U	631	0%	25	3.5	70%	33	13.2	C	D	D	C
329	Ehrlich, Turner/S Village (S)	12	4	2	D	1261	0%	45	3.5	0%	61	8.8	D	B	D	C
302	Fowler Ave at North	12	5	3	D	2119	0%	50	4.0	0%	0	26.4	D	B	D	C
327	W University at 10th (S)	12	8	2	U	165	0%	30	3.0	40%	40	20.8	D	C	D	C
309	Holly at Laurel , (S)	10	0	2	U	134	0%	20	4.0	0%	52	0.0	D	D	C	B
313	21st St at 7th Ave, (W)	10	0	3	OW	536	0%	30	3.5	0%	33	24.0	D	D	E	D
308	Holly at Magnolia , (N)	10	0	2	U	407	0%	20	4.0	0%	86	0.0	D	D	D	C
320	Fletcher Ave at 50th (S)	12	5	2	D	1898	0%	45	4.0	0%	64	0.0	E	B	D	B
321	Fletcher, 50th to 56th (S)	12	5	2	D	2146	0%	45	4.0	0%	0	15.2	E	B	D	C
318	US 41 at 31st St, (W)	12	0	3	D	182	100%	55	3.5	0%	35	24.0	E	B	F	F
322	56th St at 98th Ave, (W)	12	0	3	D	1544	0%	45	3.5	0%	0	28.7	E	B	E	D
310	Fletcher at Sebring, (S)	11.5	0	2	D	1589	0%	40	4.0	0%	0	37.0	E	B	F	E
301	Fowler, River H./Gillette	12	5	3	D	2549	0%	50	4.0	0%	0	28.9	E	B	E	D
312	7th Ave, 17th to 14th (N)	12	0	1	U	631	0%	25	3.5	0%	49	5.0	E	C	D	C
317	US 41 at Dover St, (E)	12	0	2	D	495	17%	55	3.0	0%	0	11.5	F	B	E	D
314	56th St at Busch (W)	12	0	2	D	638	0%	45	3.5	0%	142	28.7	F	B	F	F
323	56th St at Busch (W)	12	0	3	D	357	0%	45	3.5	0%	142	28.7	F	E	E	F
324	Bullard at 56th St	12	4	3	D	636	0%	45	4.0	0%	87	19.6	F	E	D	C
	% Exact Match to Video												100%	15%	27%	46%
	% Within 1 LOS of Video												100%	50%	85%	77%

CHAPTER 8

Pedestrian LOS Model

8.1 Model Development

Two basic forms were considered for the pedestrian LOS for arterials model. The first was an aggregate model that used the outputs from existing segment and intersection LOS models to determine the arterial LOS. The other was an agglomerate model that considered the independent characteristics of the roadway/walkway environment to calculate an arterial LOS for pedestrians directly. Both were preliminarily evaluated during model development.

The aggregate model was chosen for refinement for several reasons. The stepwise approach to an aggregate model is useful because it allows the practitioner to evaluate the effect of improvements at individual intersections or along specific segments on the overall LOS of the facility. The aggregate model also retains all the terms found both intuitively and mathematically validated to be significant to pedestrians walking within an urban environment. The agglomerate models form was tested during our preliminary models and did not retain all the terms as significant. Consequently, we focused on the aggregate model in our model development efforts.

We considered various functional techniques for model development, including linear regression and ordered probit. We performed linear regression modeling because it is more intuitive than probit modeling in practice and non-modelers better understand the sensitivity of the regression model. These reasons are particularly important in that these models are most frequently used: the development or analysis of specific design options or in the development of pedestrian facility community master plans with presentations to interested citizens and public officials. To ensure the validity of the results of the linear regression modeling results, we evaluated the ordered probit model form as well. The results of both the linear regression and ordered probit modeling efforts are described below.

For both modeling efforts the dependent variable, Observed pedestrian LOS, was defined as the score that a participant assigned to a specific video clip. The scores were on a scale of A (best) through F (worst). For modeling purposes, the letter grades were converted to numerical scores: A=1, B=2, C=3, D=4, E=5, and F=6.

Before starting correlations analysis and modeling, we created two data subsets from the overall dataset. The total dataset was sorted by city and LOS grade responses. A random sampling of 20% of the data representing each city and LOS grade response was taken from the overall dataset for model validation. The balance of the data, 80% of the total dataset, was used for model development.

We used SPSS 14.0 to conduct Pearson correlation analysis on the extensive array of geometric and operational variables. Subsequently, we selected the following relevant variables for additional testing:

- Segment LOS—The pedestrian LOS for roadway segments (see below).
- Intersection LOS—The pedestrian LOS for signalized intersections (see below).
- Midblock Crossing LOS—The LOS associated with midblock crossings (see below).
- Total Pedestrians—The total number of pedestrians encountered in the video clip; a measure of pedestrian space, which is an input to the existing pedestrian LOS methodology in the HCM.
- Conflicts per mile—The total conflicts per mile represent the motor vehicle conflicts resulting from motorists turning across the pedestrian facility at unsignalized locations.
- Size of the city in which the data collection took place—The MSA population was used to represent the size of each city.

The panel asked that MSA be dropped from further consideration as a variable. Other variables were dropped from further consideration because of their poor correlation with the dependent variable or because of their colinearity with more strongly correlated variables. Also, variables such as traffic volume, sidewalk width, and signal delay, are components of the segment LOS or the intersection LOS, so we did not model them independently.

Several variables were evaluated for inclusion as additional terms in the model. Frequency of unsignalized conflicts (intersections and driveways) per mile was tested for its correlation and significance to the arterial LOS for pedestrians and was not found to be a significant factor. Additionally, the density of pedestrians on the sidewalk (the current HCM measure of LOS) was not found to be significant for this model, within the low range of density values available in the video clips.

8.2 Recommended Pedestrian LOS Model

The proposed pedestrian level of service predicts the mean level of service that would be reported by pedestrians along or across the urban street. The average pedestrian LOS for the urban street facility is a function of the segment level of service, the intersection level of service, and the mid-block crossing difficulty.

Overall Pedestrian LOS Model

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

Ped LOS = Worse of (Pedestrian Density LOS, Ped Other LOS) (Eq. 33)

Where

Ped LOS = The letter grade level of service for the urban street combining density and other factors.

Ped Density LOS = The letter grade level of service for sidewalks, walkways, and street corners based on density

Ped Other LOS = The letter grade level of service for the urban street based on factors other than density

Pedestrian Density LOS Model for Sidewalks, Walkways, Street Corners

The methods of Chapter 18 of the HCM are used to compute the pedestrian density for the sidewalks and the pedestrian waiting areas at signalized intersection street corners. The LOS thresholds given in that chapter for these facilities are used to determine the level of service. The thresholds for sidewalks and walkways are given in Exhibit 93.

Pedestrian Other LOS Model

The pedestrian LOS for the facility that is representative of non-density factors is computed according to either of the two models below:

Pedestrian Other LOS Model 1

$$\text{OtherPLOS (\#1)} = (0.318\ \text{PSeg} + 0.220\ \text{PInt} + 1.606) * (\text{RCDF}) \quad \text{(Eq. 34)}$$

Pedestrian Other LOS Model 2

$$\text{OtherPLOS (\#2)} = (0.45\ \text{PSeg} + 0.30\ \text{PInt} + 1.30) * (\text{RCDF}) \quad \text{(Eq. 35)}$$

Where

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

The first model provides the better statistical fit with the video lab data. However, this model does not produce LOS F for the streets in the video clip data set. The second model is a manual modification of the parameters of the first model so that the second model will produce a full range of LOS A to F for the streets in the video clip data set. The constant was

Exhibit 93. Pedestrian Walkway LOS (Density).

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

Source: Exhibit 18-3 HCM 2000 [**110**]

manually adjusted downward and the other parameters were adjusted upward until the second model produced LOS F for at least one of the streets in the data set.

Although none of the video clips actually produced a LOS A or F rating (on average) from the video lab participants, the second model was developed to address potential public agency acceptance issues that might arise with adopting the first LOS model for pedestrians that might not produce LOS A and LOS F for at least some streets in the jurisdiction. The second model produces a full range of LOS A to F results for a reasonable range of street conditions typical of urban areas of the United States.

The output of both of these models is a numerical value, which must be translated to a LOS letter grade. Exhibit 94 provides the numerical ranges that coincide with each LOS letter grade. These thresholds are the same as for the other modes.

Pedestrian Segment LOS

The segment pedestrian LOS is calculated according to the following widely used equation [111]:

$$PLOS = -1.2276 \ln (f_{LV} \times W_t + 0.5W_l + f_p \times \%OSP + f_b \times W_b + f_{sw} \times W_s) + 0.0091 (V/(4*PHF*L)) + 0.0004\, SPD^2 + 6.0468 \quad \text{(Eq.36)}$$

Where

Ped SegLOS = Pedestrian level of service score for a segment

ln = Natural log

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

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

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

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

%OSP = Percent of segment with on-street parking

f_b = Buffer area coefficient

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

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

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

W_s = Width of widewalk

For widths greater than 10 feet, use 10 feet.

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

PHF = Peak hour factor

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

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

Exhibit 94. Pedestrian "Other" Model LOS Categories.

LOS	Numerical Score
A	≤ 2.00
B	>2.00 and ≤ 2.75
C	>2.75 and ≤ 3.50
D	>3.50 and ≤ 4.25
E	>4.25 and ≤ 5.00
F	> 5.00

Pedestrian Intersection LOS

The intersection LOS for pedestrians is computed only for signalized intersections according to the following equation developed by Petritsch et al.[112]:

$$\begin{aligned}\text{Ped Int LOS (Signal)} &= 0.00569(RTOR + PermLefts) \\ &+ 0.00013(PerpTrafVol*PerpTrafSpeed) \\ &+ 0.681(LanesCrossed^{0.514}) + 0.0401\ln(PedDelay) \\ &- RTCI(0.0027PerpTrafVol - 0.1946) + 0.5997 \qquad \text{(Eq. 37)}\end{aligned}$$

Where

RTOR +PermLefts = Sum of the number of right-turn-on-red vehicles and the number of motorists making a permitted left turn in a 15-minute period

PerpTrafVol*PerpTrafSpeed = Product of the traffic in the outside through lane of the street being crossed and the midblock 85th percentile speed of traffic on the street being crossed in a 15-minute period

LanesCrossed = The number of lanes being crossed by the pedestrian

PedDelay = Average number of seconds the pedestrian is delayed before being able to cross the intersection

RTCI = Number of right turn channelization islands on the crossing.

Pedestrian Midblock Crossing Factor

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

$$RCDF = Max[0.80, Min\{[(XLOS\#-NXLOS\#)/7.5 + 1.00], 1.20\}] \qquad \text{(Eq. 38)}$$

Where

RCDF = Roadway crossing difficulty factor

XLOS# = Roadway crossing difficulty LOS Number

NXLOS# = Non-crossing Pedestrian LOS number

= (0.318 PSeg + 0.220 PInt + 1.606)

Pseg = Ped. Segment LOS number (computed per equation #20)
Pint = Ped. Intersection LOS number (computed per equation #21)

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

$$XLOS = \text{Min}\,[\text{WaitForGap}, \text{DivertToSignal}] \qquad \text{(Eq. 39)}$$

Where
XLOS = Crossing LOS score (based on Exhibit 96)
WaitForGap = Delay waiting for safe gap to cross.
DivertToSignal = Delay diverting to nearest signalized intersection to cross.

The delay is converted into a LOS numerical score based on the minimum of the mean delay waiting for a gap or diverting to a signal, according to the values given in Exhibit 95.

Wait-For-Gap LOS Calculation

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

Acceptable Gap = (Number of Lanes * 12 feet/lane) / 3.5 feet/second + 2 seconds (Eq. 40)

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

$$MeanWait = \frac{1}{\lambda}\left[\exp(\lambda t) - 1\right] - t \qquad \text{(Eq. 41)}$$

Where
t = The acceptable gap plus the time it takes for a vehicle to pass by the pedestrian.
The average pass-by time = Average Vehicle Length/ Average Speed, converted to seconds.
λ = The average vehicle flow rate in vehicles per second.
Exp = The exponential function

Exhibit 95. Pedestrian Crossing LOS Score.

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

Using the numerical cutoffs shown in Exhibit 96 the final numerical score is then interpolated between the cutoff values based on the probability of obtaining an adequate gap within the allowed time.

For this calculation, the increasing LOS numerical score is assumed to become logarithmic beyond LOS F.

Divert To Signal LOS

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

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

Ped Geometric Delay = 2/3 * (Block Length)/ Ped Walking Speed (Eq. 42)

The control delay at the intersection is calculated as shown in the HCM [**113**]:

Ped Control Delay = (Cycle Length − Green Time)^2/ (2*Cycle Length) (Eq. 43)

The total delay is the sum of the two:

Total Ped Deviation Delay = Ped Geometric Delay + Ped Cycle Delay (Eq. 44)

Exhibit 96. Pedestrian LOS and Delay Thresholds.

Pedestrian LOS	Delay Threshold Seconds	Equivalent LOS Numerical Score Range	Equivalent LOS Midpoint Score
A	10	≤ 1.5	1
B	20	>1.5 and ≤ 2.5	2
C	30	> 2.5 and ≤ 3.5	3
D	40	> 3.5 and ≤ 4.5	4
E	60	> 4.5 and ≤ 5.5	5
F	> 60	> 5.5	6

For this calculation, the increasing LOS numerical score is assumed to become logarithmic beyond LOS F.

Exhibit 97. Evaluation of Proposed Pedestrian Model and HCM Against Video Lab Results.

Clip	Location	Sidewalk Width (ft)	Pedestrian Flow Rate (pph)	Outside Lane (ft)	Shoulder Width (ft)	On-Street Parking (%)	Barrier (Y/N)	Buffer Width (ft)	Dir. Vol. (vph)	Traffic Lanes (lanes)	Traffic Speed (mph)	Video LOS	HCM LOS	Model #1 LOS	Model #2 LOS
215	7th Ave at 15th St, N side	8	60	12	0	50%	Yes	7	170	1	25	B	E	B	B
227	Grant Ave at California St, E side	6	200	16	0	0%	Yes	4	630	2	30	B	B	C	C
230	3rd St at Mission St, E side	6	220	12	0	0%	No	5	220	2	30	B	D	C	D
221	Stockton St at Washington St, E side	4	640	16	0	0%	Yes	3	0	1	30	B	E	B	B
224	Grant Ave at Jackson St, E side	4	1320	12	0	100%	Yes	2	80	1	30	B	E	B	B
228	Post St at Stockton St, S side	6	180	10	0	40%	Yes	1	370	1	30	B	D	B	C
226	Geary Blvd at Divisadero St, S side	9	190	20	0	50%	Yes	5	1180	2	40	B	D	D	D
232	Hillsborough, Arm. to Tamp., N side	6	0	16	4	0%	No	0	540	1	45	B	B	D	D
229	Post St at Stockton St, S side	6	280	10	0	40%	Yes	0	310	1	30	B	D	B	B
205	Alumni Dr at Magnolia Dr, N side	10	0	12	4	0%	No	10	200	2	30	C	B	C	C
211	Bearss Ave at North Blvd, N side	4	0	12	0	0%	No	5	570	1	45	C	A	B	C
214	Dale Mabry at Tampa Bay, E side	9.5	0	12	5	0%	No	35	2030	3	45	C	E	D	E
225	Geary Blvd at Divisadero St, S side	9	280	20	0	50%	Yes	5	1050	2	40	C	C	D	D
218	Market St at Kearney St, N side	15	340	12	0	0%	No	12	60	1	30	C	C	B	B
222	Stockton St at Broadway St, E side	6	610	16	0	50%	Yes	3	220	2	30	C	E	C	C
219	Stockton St at Clay St, E side	7	640	16	0	100%	Yes	4	150	1	30	C	E	B	B
220	Stockton St at Clay St, E side	7	820	16	0	100%	Yes	4	150	1	30	C	D	B	B
223	Stockton St at Broadway St, E side	6	1600	16	0	50%	Yes	3	0	2	30	C	D	A	A
210	Magnolia Dr at Holly Dr, W side	0	0	12	0	0%	No	0	160	2	30	C	C	C	C
216	21st St at 7th Ave, W side	6	0	12	0	0%	No	0	360	1	30	C	A	C	C
217	21st St at 7th Ave, W side	6	0	12	0	0%	No	0	300	1	30	C	E	B	C
203	Collins Blvd at Alumni Dr, E side	10	0	12	4	0%	No	15	270	2	30	D	D	C	C
204	Collins Blvd at Alumni Dr, E side	10	0	12	4	0%	No	15	160	2	30	D	E	B	C
231	Dale Mabry, State to Carmen, W side	5	0	12	0	0%	No	6	570	1	35	D	B	D	D
201	Holly Dr at Magnolia Dr, N side	0	0	10	0	0%	No	0	270	2	20	D	E	D	E
209	Fletcher at Bruce B Downs, S side	0	0	12	4	0%	No	0	2170	4	45	D	A	E	F
206	Fowler Ave at 56th St, S side	5	0	12	5	0%	No	23	1690	4	50	E	E	D	E
208	Fletcher at Bruce B Downs, S side	0	30	12	4	0%	No	0	1750	4	45	E	C	E	F
	% Exact Match to Video Rating											100%	25%	43%	43%
	% Within 1 LOS of Video Rating											100%	43%	86%	79%

Notes:

- On-Street Parking = Percent of on-street parking lane occupied by parked vehicles.
- Barrier is presence of trees, or other barrier between pedestrian sidewalk and street.
- Traffic lanes is number of lanes in direction of travel closest to pedestrian.
- Video LOS is the mean of the letter grade LOS ratings reported by subjects in video lab.
- Model LOS is the LOS grade predicted by the proposed pedestrian LOS model.

The total delay is then converted into a numerical LOS score by linearly interpolating numerical scores on the scale provided in Exhibit 96.

8.3 Performance Evaluation of Pedestrian LOS Model

Exhibit 97 compares the performance of the proposed pedestrian LOS model (with the mid-block crossing factor) to the mean LOS rating for each pedestrian video clip. The video clips did not expose lab subjects to any arterial mid-block crossing situations. Although the HCM reproduces the mean video lab ratings for each video clip 25% of the time, the two proposed pedestrian LOS models (1 and 2) both reproduce the mean video clip ratings 43% of the time. The difference is that Model 2 produces LOS A to F results for the streets in the video clip data set. Model 1 produces LOS A to E results for the same streets.

CHAPTER 9

Integrated Multimodal LOS Model Framework

This section provides an overview of the proposed urban street LOS framework and the proposed LOS modeling system.

9.1 The Framework

The proposed multimodal LOS framework for urban streets reports a single average level of service for each of four modal users of the urban street:

1. Auto drivers,
2. Bus passengers,
3. Bicycle riders, and
4. Pedestrians.

The individual modal levels of service are NOT combined into a single comprehensive level of service for the facility because this would disguise the disparities in the perceptions of quality of service for the four modes.

The urban street LOS for a given mode is defined as the *average* degree of satisfaction with the urban street that would be reported by a large group of travelers using that mode of travel *if they had traveled the full length* of the study section of the street. The video lab research showed that the degree of satisfaction experienced by an individual traveler for a given situation varies widely across individuals. Consequently, this framework focuses on predicting the average degree of satisfaction of a large group of people exposed to the same urban street experience. Due to fatigue effects, travelers actually traveling the full length of the facility would forget key aspects of their experience and report a different level of service than would several travelers traveling short lengths of the facility. This framework takes the LOS perceptions of travelers on short sections of urban street and compiles them into an estimate of LOS for the full length of the street.

The six-letter grade A-F LOS structure of the HCM has been preserved. Many of the statistical results suggest that people can actually distinguish only two to three levels of service. However, public agency planners and engineers need to be able to predict how close a facility is to an unacceptable level of service. So the six levels have been retained for agency planning purposes, rather than because people actually can distinguish among them.

Level of service is defined for each mode as shown in Exhibit 98.

9.2 The Integrated LOS Modeling System

The proposed LOS modeling system relies on 37 variables to predict the perceived degree of satisfaction experienced by travelers on the urban street. These variables consist of four basic types: facility design, facility control, transit service characteristics, and the volume of vehicle traffic on the facility.

Input Variable Interactions Among Modes

Exhibit 99 lists the input variables and their major interactions. Minor interactions are not shown in this exhibit, but are discussed below.

The Auto LOS Model 1 uses two variables: Auto Stops Per Mile, and Presence of Left-Turn Lanes.

- The presence of a left-turn lane is a facility design feature.
- The stops per mile are directly influenced by the intersection control type and the settings of the traffic signal. High auto and transit volumes can increase the probability of stopping. Pedestrian and bicycle volumes at intersections reduce the saturation flow rate, which reduces speed and increases stops.

The Auto LOS Model 2 uses two variables: Percent of Posted Speed Limit, and Median Type.

Exhibit 98. Definition of LOS by Mode.

Level of Service	Auto	Transit	Bicycle	Pedestrian
A	Best Performance	Very Satisfied	Best Performance	Best Performance
B				
C				
D				
E				
F	Worst Performance	Very Dissatisfied	Worst Performance	Worst Performance

Exhibit 99. Interaction of Modal LOS Model Inputs.

Inputs to LOS Models	Facility Design	Facility Control	Transit Service	Auto Volume	Transit Volume	Bicycle Volume	Pedestrian Volume
Auto LOS Model #1							
Auto Stops (or Delay)		XXX		XXX	XXX	XXX	XXX
Left Turn Lanes	XXX						
Auto LOS Model #2							
Mean Speed		XXX		XXX	XXX	XXX	XXX
Median Type	XXX						
Transit LOS Model							
Pedestrian LOS	XXX	XXX		XXX	XXX		XXX
Bus Headway			XXX				
Bus Speed		XXX		XXX	XXX	XXX	XXX
Bus Schedule Adherence			XXX	XXX	XXX	XXX	XXX
Passenger Load					XXX		
Bus Stop Amenities	XXX						
Bicycle LOS Models							
Bike-Pedestrian Conflicts*	XXX					XXX	XXX
Driveway Conflicts/Mile	XXX						
Vehicles Per Hour				XXX	XXX		
Vehicle Through Lanes	XXX						
Auto Speed	XXX	XXX		XXX	XXX		
Percent Heavy Vehicles				XXX	XXX		
Pavement Condition	XXX			XXX	XXX		
Width of Outside Lane	XXX						
On-Street Parking Occupancy	XXX	XXX					
Cross Street Width	XXX						
Pedestrian LOS Models							
Pedestrian Density	XXX						XXX
Pedestrian-Bike Conflicts*	XXX					XXX	XXX
Width of Shoulder	XXX						
Width of Outside Lane	XXX						
On-Street Parking Occupancy	XXX						
Presence of Trees	XXX						
Sidewalk Width	XXX						
Distance To Travel Lane	XXX						
Vehicles Per Hour				XXX	XXX		
Vehicle Through Lanes	XXX						
Average Vehicle Speed	XXX	XXX		XXX	XXX	XXX	XXX
Right Turns On Red	XXX	XXX		XXX			XXX
Cross Street Speed	XXX	XXX					
Cross Street Vehicles/Hour				XXX	XXX		
Cross Street Lanes	XXX						
Crossing Delay		XXX					
Right-Turn Channelization	XXX						
Block Length	XXX						
Signal Cycle Length		XXX		XXX	XXX		XXX
Signal Green Time		XXX		XXX	XXX		XXX

"XXX" indicates that input variable is influenced by that factor.
* Ped/bike conflicts come into play only for paths outside of roadway but within right-of-way of street.

- The Median Type is a facility design feature.
- The percent of posted speed limit that traffic is able to travel the full length of the street is directly influenced by the intersection control type and the settings of the traffic signal. High auto and transit volumes can reduce the mean speed. Pedestrian and bicycle volumes at intersections reduce the saturation flow rate, which reduces mean auto speed.

The Transit LOS Model uses 6 variables: Pedestrian LOS, Bus Headway, Bus Speed, Bus On-Time Performance, Passenger Load, and Bus Stop Amenities.

- The pedestrian LOS is determined by the facility design, intersection controls, the volume of auto and transit traffic, and the pedestrian volume (pedestrian volumes influence signal timing, which affects signal delay for pedestrians, which affects pedestrian LOS).
- The bus headway is determined by the transit service provider, which is related to the passenger loads.
- Bus speed is determined by the facility controls (signal settings), the amount of auto and transit traffic, and the number of boarding passengers at each stop. Bicycles in the travel lanes may delay buses. Heavy pedestrian volumes at intersections (or mid-block) may delay buses.
- Bus on-time performance is determined by the service provider (e.g., number of back up buses, and maintenance to prevent breakdowns). It is also influenced by the auto, bicycle, and pedestrian volumes on the street.
- Passenger load is determined by the density of development in the area, the relative convenience of other modes of travel, and the bus headways provided by the transit operator.
- Bus stop amenities are a design feature of the facility.

The Bicycle LOS Model uses the following variables: Driveway Conflicts/Mile, Vehicles Per Hour, Vehicle Through Lanes, Speed Limit, Percent Heavy Vehicles, Pavement Condition, Width of Outside Lane, On-Street Parking Occupancy, and Cross Street Width.

- Bicycle-Pedestrian Conflicts (only if bicycles share the pedestrian facility).
- Driveway Conflicts/Mile are a design feature.
- Vehicles Per Hour is determined by the auto, truck, and transit volumes.
- Vehicle Through Lanes is a design feature of the facility.
- Speed Limit is a control feature of the facility. It is influenced by the facility design.
- Percent Heavy Vehicles is influenced by the auto, truck, and transit volumes.
- Pavement Condition is a facility maintenance feature. It is influenced by auto, truck, and transit volumes and the pavement design.
- Width Of Outside Lane is a design feature.
- On-Street Parking Occupancy is determined by the parking controls, available off-street parking, and the density of land uses in the area. Facility design determines whether a parking lane is provided and whether or not parking is prohibited during peak hours.
- Cross Street Width is determined by the facility design.

The Pedestrian LOS Model uses the following variables: Pedestrian Density, Bicycle-Pedestrian Conflicts (if facility is shared), Width of Shoulder, Width of Outside Lane, On-Street Parking Occupancy, Presence of Trees, Sidewalk Width, Distance To Travel Lane, Vehicles Per Hour, Vehicle Through Lanes, Average Vehicle Speed, Right-Turns on Red, Cross Street Speed, Cross Street Vehicles/Hour, Cross Street Lanes, Crossing Delay, Right-Turn Channelization, Block Length, Signal Cycle Length, Signal Green Time

- Pedestrian Density (Computed according to HCM).
- Bicycle-Pedestrian Conflicts (only if bicycles share the pedestrian facility).
- Width of Shoulder is a design feature.
- Width of Outside Lane is a design feature
- On-Street Parking Occupancy is determined by the parking controls, available off-street parking, and the density of land uses in the area. Facility design determines whether a parking lane is provided and whether or not parking is prohibited during peak hours.
- Presence of Trees is a design feature.
- Sidewalk Width is a design feature.
- Distance to Travel Lane is a design feature.
- Vehicles Per Hour is determined by the auto, truck, and transit volumes.
- Vehicle Through Lanes is a design feature of the facility.
- Average Vehicle Speed is determined by the facility design, the facility control (speed limit), and the auto, bus, bicycle, and pedestrian volumes on the facility, to the extent that bicycles and pedestrians share (or cross) the traveled way used by motor vehicles.
- Right-Turns on Red are determined by the facility control (are they allowed?). They are influenced by the auto and transit volumes. Heavy pedestrian volumes may reduce the ability of autos or buses to turn right on red.
- Cross Street Speed is determined by the design and control of the cross street. It is influenced by cross-street volumes. Heavy pedestrian or bicycle volumes may reduce the cross street speed.
- Cross Street Vehicles/Hour is determined by the auto and transit volume.
- Cross Street Lanes is a design feature. It is influenced by the auto and transit volumes.
- Crossing Delay is determined by the intersection control (signal timing), which in turn is influenced by auto, bus, and pedestrian volumes.

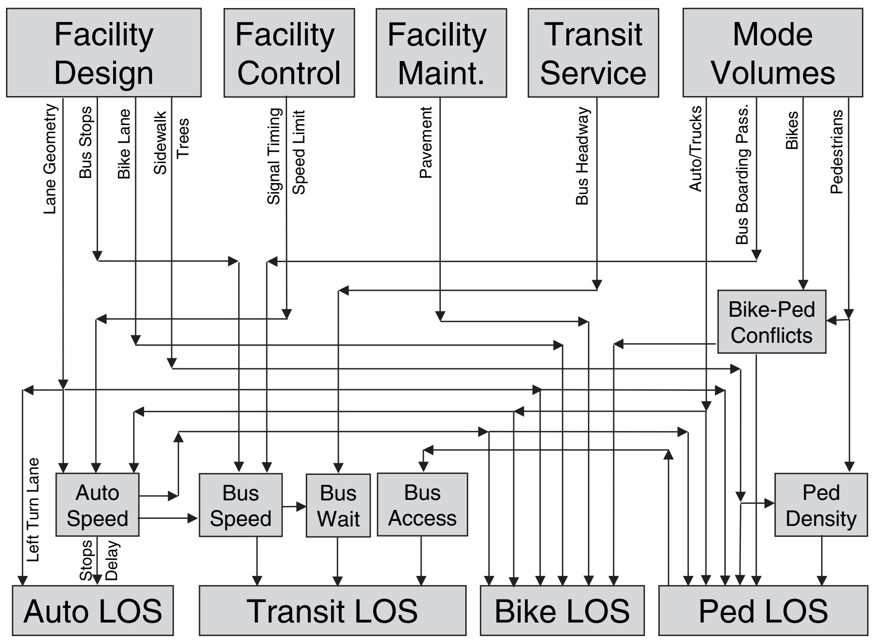
- Right-Turn Channelization is a design feature.
- Block Length is a design feature
- Signal Cycle Length is a facility control feature. It is influenced by the facility design, auto and transit volumes, and the pedestrian volumes.
- Signal Green Time is a facility control feature. It is influenced by the facility design, auto and transit volumes, and the pedestrian volumes.

Interactions Among Modal LOS Results

Exhibit 100 shows the major interactions among the input variable types, the modal LOS models, and the modal LOS model results.

To estimate the variables required by the LOS models, the analyst first collects data on facility design, facility control, facility maintenance, transit service, and the volume for each mode. The analyst uses these data to estimate various modal performance characteristics (auto speed, bus speed, bus wait, bus access, bicycle-pedestrian conflicts if a shared facility is present, and pedestrian density). Once the modal performance characteristics are known, then the methods of NCHRP 3-70 are used to estimate auto LOS, transit LOS, bicycle LOS, and pedestrian LOS for the urban street. The bicycle-pedestrian conflict LOS is estimated using procedures in Chapters 18 and 19 of the HCM.

Exhibit 100. LOS Model Interactions.



CHAPTER 10

Accomplishment of Research Objectives

Exhibit 101 illustrates how the recommended modeling system meets the research objectives.

Exhibit 101. Satisfaction of Research Objectives by the Recommended Modeling System.

Research Objective	Degree Accomplished By Proposed Model System
1. Produce updated chapter on multimodal LOS analysis for urban streets for Highway Capacity Manual. Produce sample problems. Produce software engine.	Draft chapter, sample problems, and software engine delivered to panel in June 2007 and to Highway Capacity Committee in July 2007. Final Report delivered February 2008.
2. Establish a scientific basis for evaluating level of service as a function of traveler satisfaction.	The research has established a measurable definition of level of service and a reproducible method for measuring it. The model system is based on video labs and field surveys conducted in several cities in the United States.
3. Create a consistent set of modal LOS models allowing for comparison of degrees of modal traveler satisfaction across of modes.	The uniform definition of LOS used in the models provides a consistent basis for comparing levels of service across modes.
4. Provide a multimodal LOS system that takes into account interactions among modes in the urban street environment.	The multimodal LOS system takes into account the impacts of autos, buses, bicycles, and pedestrians on the perceived LOS for each mode. Many cross-modal factors are taken into account directly, others are incorporated indirectly. Explicit numerical methodologies do not yet exist for incorporating the indirect effects into the LOS models, but the "hooks" are in place in the LOS models for future incorporation of new methods for estimating the indirect effects.
5. Create a multimodal LOS system that is applicable to arterials and major collectors	The LOS system is applicable to arterials and major collectors.
6. Create a multimodal LOS system that addresses all vehicle and pedestrian movements.	The multimodal LOS system concept allows the consideration of all movements by vehicles and pedestrians. The LOS models themselves have been implemented primarily for through travel along the arterial or collector. The pedestrian model, in addition, incorporates mid-block crossing.
7. Create a multimodal LOS system that can be used to evaluate micro-peaks (less than 15 minutes).	The LOS system can be applied to peaks shorter than 15 minutes; however, the models that implement that system are designed for 15 minute peaks.
8. Incorporate safety and economic aspects only insofar as they influence perceptions of LOS.	Safety and economic effects have not been explicitly included or excluded from the LOS models. Laboratory and field survey participants were allowed to consider any aspect of the service provided in determining their perceived levels of service.
9. Overcome the nine limitation of the HCM listed in Chapter 15 of the HCM.	a. The presence or lack of parking is included in the bicycle and pedestrian LOS models. It indirectly affects the auto and transit LOS models. b. Driveway density and access control is included in the bicycle LOS model. c. Short lane additions and drops are not explicitly included in any of the LOS models. d. The impacts of road gradients are not included in the currently proposed LOS models, but could be added. e. Capacity constraints between intersections are taken into account to the extent they affect stops by autos or delay bus service. f. Two-way left turn lanes and medians are not explicitly included in the LOS models but can indirectly affect auto and bus LOS by reducing stops, or increasing bus speeds. g. High percentage turning movements explicitly affect pedestrian LOS. They indirectly affect auto and bus LOS. h. Multi-block queues will cause problems for the auto LOS model, which considers only stops. Under the recommended model, a single stop for a long queue gives better auto LOS than multiple stops for several short queues. i. Cross street congestion blocking through traffic will indirectly affect auto and bus LOS and will directly impact pedestrian LOS.

References

1. *The Highway Capacity and Quality of Service Manual*, Transportation Research Board, National Research Council, Washington, DC (2000).
2. *TCRP Web-Only Document 6: Transit Capacity and Quality of Service Manual*, Transportation Research Board, National Research Council, Washington, DC (1999).
3. *2002 Quality/Level of Service Handbook*, Florida Department of Transportation, Office of the State Transportation Planner, Systems Planning Office, Tallahassee, FL (January 7, 2003). (http://www11.myflorida.com/planning/systems/sm/los/)
4. Rouphail, N., et al. "Recommended Procedures for Chapter 14, Bicycles, of the Highway Capacity Manual." *Report FHWA-RD-98-108*. FHWA, U.S. DOT (1998).
5. Rouphail, N., et al. "Recommended Procedures for Chapter 13, Pedestrians, of the Highway Capacity Manual." *Report FHWA-RD-98-107*. FHWA, U.S. DOT (1999).
6. Fruin, J. *Pedestrian Planning and Design*. Metropolitan Association of Urban Designers and Environmental Planners, New York, NY (1971).
7. Botma, H. "Method to Determine Level of Service for Bicycle Paths and Pedestrian Bicycle Paths." *Transportation Research Record 1502*, Transportation Research Board, National Research Council, Washington, DC, pp. 38–44 (1995).
8. Pushkarev, B. and J. Zupan. *Public Transportation and Land Use Policy,* Indiana University Press, Bloomington, IN (1977).
9. Phillips, R., J. Karachepone, and B. Landis. Multi-Modal Quality of Service Project, Urban and Regional Planning Department, University of Florida, Gainesville, FL (March 2001).
10. Flannery, A., K. Wochinger, and A. Martin. "Driver Assessment of Service Quality on Urban Streets." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2005).
11. Flannery, A., et al. "Research Approaches to Assess Automobile Drivers' Perception of Quality of Service." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2004).
12. Colman, S. "Assessing Arterial Level of Service for Congestion Management Programs: A User Perspective," 1994 ITE International Conference, Institute of Transportation Engineers, Washington, DC (1994).
13. Pecheux, K., et al. "Automobile Drivers' Perceptions of Service Quality on Urban Streets." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2004).
14. Science Applications International Corporation, George Mason University, and Volpe National Transportation Systems Center. "Quality of Service and Customer Satisfaction on Arterial Streets: Final Report." FHWA, U.S. DOT, Washington, DC, June 13 (2003).
15. Sutaria, T., and J. Haynes. "Level of Service at Signalized Intersections," *Transportation Research Record 644*, Transportation Research Board, National Research Council, Washington, DC (1977).
16. Ha, T.-J., Tae-Jun Ha and W. Berg. "Development of Safety-Based Level-Of-Service Criteria for Isolated Signalized Intersections," *Transportation Research Record 1484*, Transportation Research Board, National Research Council, Washington, DC (1995).
17. Zhang, L., and P. Prevedouros. "Signalized Intersection LOS that Accounts for Safety Risk." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
18. Zhang, L., and P. Prevedouros. "Signalized Intersection LOS that Accounts for User Perceptions." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2004).
19. Zhang, L., and P. Prevedouros. "User Perceptions of Signalized Intersection Level of Service." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2005).
20. Li, J., Z. Yue, and S. Wong. "Performance Evaluation of Signalized Urban Intersections under Mixed Traffic Conditions by Gray System Theory." *Journal of Transportation Engineering*, Vol. 130, No. 1, pp. 113-121 (2004).
21. Pecheux, K., M. Pietrucha, and P. Jovanis. "User Perception of Level of Service at Signalized Intersections: Methodological Issues," *Transportation Research Circular E-C018*, Fourth International Symposium on Highway Capacity, Transportation Research Board, Washington, DC (June 2000).
22. Fang, C., and K. Pecheux. "Analysis of User Perception of Level of Service Using Fuzzy Data Mining Technique." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2007).
23. Zhang, L., and P. Prevedouros. "Fuzzy Logic Based User Perceptions of Signalized Intersection Level of Service." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2007).
24. Lee, D., T.-G. Kim, and M. Pietrucha. "Incorporation of Transportation User Perception Into Evaluation of Service Quality of Signalized Intersections Using Fuzzy Aggregation." Presented

at the Transportation Research Board Annual Meeting, Washington, DC (2007).

25. Nakamura, H., K. Suzuki, and S. Ryu. "Analysis of the Interrelationship Among Traffic Flow Conditions, Driving Behavior, and Degree of Driver's Satisfaction on Rural Motorways," *Transportation Research Circular E-C018*, Fourth International Symposium on Highway Capacity, Transportation Research Board, Washington, DC (June 2000).
26. Fu, L., F. Saccomanno, and Y.Xin. "A New Performance Index for Evaluating Transit Quality of Service." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2005).
27. Tumlin, J., et al. "Performance Measures for the Urban Village Transit Network." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2005).
28. Xin, Y., L. Fu, and F. Saccomanno. "Assessing Transit Level of Service along Travel Corridors Using TCQSM – A Case Study." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2005).
29. Furth, P., and T. Muller. "Service Reliability and Hidden Waiting Time: Insights from AVL Data." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2006).
30. Morpace International, Inc., , *TCRP Report 47: A Handbook for Measuring Customer Satisfaction and Service Quality*, Transportation Research Board, National Research Council, Washington, DC (1999).
31. Kittelson & Associates, Inc., et al. *TCRP Report 88: A Guidebook for Developing a Transit Performance-Measurement System,* Transportation Research Board, National Research Council, Washington, DC (2003).
32. Perk, V., and C. Foreman, "Evaluation of First-Year Florida MPO Transit Capacity and Quality of Service Reports," *Report NCTR-473-02*, National Center for Transit Research, University of South Florida, Tampa, FL (2001).
33. Petritsch, T. "Video Simulation of Roadway Bicycling." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2007).
34. Zolnik, E., and E. Cromley. "Poisson Multilevel Bicycle Level-Of-Service Methodology for Road Networks." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2007).
35. Petritsch, T., et al. "Bicycle Level of Service for Arterials." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2007).
36. Petritsch, T. "Video Simulation of Roadway Bicycling." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2007).
37. Jensen, S. "Pedestrian and Bicycle Levels of Service on Roadway Segments." Presented at the Transportation Research Board Annual Meeting, Washington DC (2007).
38. Landis, B., et al. "Intersection Level of Service: The Bicycle Through Movement." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
39. Harkey, D., D. Reinfurt, and M. Knuiman. "Development of the Bicycle Compatibility Index", *Transportation Research Record 1636*, Transportation Research Board, National Research Council, Washington, DC (1998).
40. Landis, B., V. Vattikuti, and M. Brannick. "Real-Time Human Perceptions: Towards a Bicycle Level of Service," *Transportation Research Record 1578*, Transportation Research Board, National Research Council, Washington, DC (1997).
41. Stinson, M., and C. Bhat. "An Analysis of Commuter Bicyclist Route Choice Using a Stated Preference Survey." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
42. Jones, E., and T. Carlson. "Development of a Bicycle Compatibility Index for Rural Roads in Nebraska." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
43. Noel, N., C. Leclerc, and M. Lee-Gosselin. "CRC Index: Compatibility of Roads for Cyclist in Rural and Urban Fringe Areas." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003a).
44. Hubbard, S., R. Awwad, and D. Bullock. "New Perspective on Assessing Impact of Turning Vehicles on Pedestrian Level of Service at Signalized Intersections." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2007).
45. Chilukuri, V., and M. Virkler. "Validation of HCM Pedestrian Delay Model for Interrupted Facilities," *Journal of Transportation Engineering*, Vol. 131, No. 12, pp. 939–945 (2005).
46. Clark, Z., S. Hubbard, and D. Bullock. "Quantitative Measurement Procedures for Pedestrian Service at Signalized Intersections: A Case Study at a Skewed Intersection." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2006).
47. Lee, J., P. Goh, and W. Lam. "New Level-of-Service Standard for Signalized Crosswalks with Bi-Directional Pedestrian Flows." *Journal of Transportation Engineering*, Vol. 131, No. 12, pp. 957–960 (2005).
48. Muraleetharan, T., et al. "Evaluation of Pedestrian Level-of-Service on Sidewalks and Crosswalks Using Conjoint Analysis." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2004a).
49. Petritsch, T., et al. "Level of Service Model for Signalized Intersections for Pedestrians." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2005).
50. Jensen, S. "Pedestrian and Bicycle Levels of Service on Roadway Segments." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2007).
51. Bian, Y., et al. "Pedestrian Level of Service for Sidewalks in China." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2007).
52. Byrd, J., and V. Sisiopiku. "Comparison of Level of Service Methodologies for Pedestrian Sidewalks." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2006).
53. Muraleetharan, T., and T. Hagiwara. "Overall Level of Service of the Urban Walking Environment and Its Influence on Pedestrian Route Choice Behavior: Analysis of Pedestrian Travel in Sapporo, Japan." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2007).
54. Hummer, J., et al. "User Perceptions of the Quality of Service on Shared Paths." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2005).
55. Patten, R., et al. "Shared Use Path Bicycle Level of Service Procedure." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2005).
56. Petritsch, T., et al. "Pedestrian Level of Service Model for Urban Arterial Facilities with Sidewalks." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2005).
57. Muraleetharan, T., et al. "Method to Determine Overall Level-of-Service of Pedestrians on Sidewalks and Crosswalks Based on

Total Utility Value." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2004b).

58. Sisiopiku, V., X. Zhang, and M. Virkler. "Pedestrian Level of Service and Quality of Operations Assessment Methods." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2002).
59. Landis, B., et al. "Modeling the Roadside Walking Environment: Pedestrian LOS," *Transportation Research Record 1773*, Transportation Research Board, Washington, DC (2001).
60. Miller, J., J. Bigelow, and N. Garber. "Calibrating Pedestrian Level-of-Service Metrics with 3-D Visualization." *Transportation Research Record 1705*, TRB, National Research Council, Washington, DC (2000) pp. 9-15.
61. Chu, X., and M. Baltes. *Pedestrian Mid-block Crossing Difficulty*, National Center for Transit Research, University of South Florida, Tampa, FL (2001).
62. Chu, X., M. Guttenplan, and M. Baltes. "Why People Cross Where They Do, The Role of the Street Environment." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
63. Winters, P. L., and L. E. Tucker. "Searching for Creative Solutions for Assessing Level of Service Equally Across Modes." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2004).
64. Perone, J., et al. "Assessing Hierarchy of Needs in Levels of Service." *FDOT BD 549-1*, National Center for Transit Research, Tampa, FL (2005).
65. Hiatt, R. E. "An Alternative to Auto LOS for Transportation Impact Analysis." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2006).
66. Winters, P., et al. *Assessing Level of Service Equally Across Modes*, Center for Urban Transportation Research, College of Engineering, University of South Florida, Tampa Bay, FL (December 2001).
67. Crider, L., J. Burden, and F. Han. Multimodal LOS: Point Level of Service Project Final Report, Department of Urban & Regional Planning, University of Florida, Gainesville, FL (August 2001).
68. Dowling, R., Florida Intrastate Highway System, Multi-Modal Corridor Level of Service Analysis, Final Report, Florida Department of Transportation, Office of the State Transportation Planner, Systems Planning Office, Tallahassee, FL (June 2001).
69. Phillips, R., J. Karachepone, and B. Landis, Multi-Modal Quality of Service Project, Urban and Regional Planning Department, University of Florida, Gainesville, FL (March 2001).
70. Guttenplan, M., et al. "Multimodal Level-Of-Service Analysis At Planning Level," *Transportation Research Record 1776*, Transportation Research Board, Washington, DC (2001).
71. Guttenplan, M., et al. "Planning Level Areawide Multi-Modal Level of Service (LOS) Analysis." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
72. Trochim, W. *Research Methods Knowledgebase*, A web-based textbook, http://trochim.human.cornell.edu/kb/, Cornell University (2002).
73. Noel, N., C. Leclerc, and M. Lee-Gosselin. "CRC Index: Compatibility of Roads for Cyclist in Rural and Urban Fringe Areas." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
74. Landis, B., et al. "Intersection Level of Service: The Bicycle Through Movement." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
75. Landis, B., V. Vattikuti, and M. Brannick. "Real-Time Human Perceptions: Towards a Bicycle Level of Service," *Transportation Research Record 1578*, Transportation Research Board, Washington, DC (1997).
76. Pecheux, K., M. Pietrucha, and P. Jovanis. "User Perception of Level of Service at Signalized Intersections: Methodological Issues," *Transportation Research Circular E-C018*, Fourth International Symposium on Highway Capacity, Transportation Research Board, Washington, DC (June 2000).
77. Sutaria, T., and J. Haynes. "Level of Service at Signalized Intersections," *Transportation Research Record 644*, Transportation Research Board, Washington, DC (1977).
78. Hall, F., S. Wakefield, and A. Al-Kaisy, "Freeway Quality of Service: What Really Matters to Drivers and Passengers?" *Transportation Research Record 1776*, Transportation Research Board, Washington, DC (2001).
79. Pecheux, K., M. Pietrucha, and P. Jovanis. "User Perception of Level of Service at Signalized Intersections: Methodological Issues," *Transportation Research Circular E-C018*, Fourth International Symposium on Highway Capacity, Transportation Research Board, Washington, DC (June 2000).
80. Sutaria, T., and J. Haynes. "Level of Service at Signalized Intersections," *Transportation Research Record 644*, Transportation Research Board, Washington, DC (1977).
81. Nakamura, H., K. Suzuki, and S. Ryu. "Analysis of the Interrelationship Among Traffic Flow Conditions, Driving Behavior, and Degree of Driver's Satisfaction on Rural Motorways," *Transportation Research Circular E-C018*, Fourth International Symposium on Highway Capacity, Transportation Research Board, Washington, DC (June 2000).
82. Colman, S. "Assessing Arterial Level of Service for Congestion Management Programs: A User Perspective," 1994 ITE International Conference, Institute of Transportation Engineers, Washington, DC (1994).
83. Morpace International, Inc. *TCRP Report 47: A Handbook for Measuring Customer Satisfaction and Service Quality*, Transportation Research Board, National Research Council, Washington, DC (1999).
84. Landis, B. W., et al. "Intersection Level of Service: The Bicycle Through Movement." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
85. Harkey, D., D. Reinfurt, and M. Knuiman. "Development of the Bicycle Compatibility Index," *Transportation Research Record 1636*, Transportation Research Board, Washington, DC (1998).
86. Jones, E., and T. Carlson. "Development of a Bicycle Compatibility Index for Rural Roads in Nebraska." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
87. Noel, N., C. Leclerc, and M. Lee-Gosselin, "CRC Index: Compatibility of Roads for Cyclist in Rural and Urban Fringe Areas." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003b).
88. Landis, B., V. Vattikuti, and M. Brannick. "Real-Time Human Perceptions: Towards a Bicycle Level of Service," *Transportation Research Record 1578*, Transportation Research Board, Washington, DC (1997).
89. Stinson, M., and C. Bhat. "An Analysis of Commuter Bicyclist Route Choice Using a Stated Preference Survey." Presented at the Transportation Research Board Annual Meeting, Washington, DC (2003).
90. Miller, J., J. Bigelow, and N. Garber. "Calibrating Pedestrian Level-of-Service Metrics with 3-D Visualization." *Transportation Research Record 1705*, Transportation Research Board, National Research Council, Washington, DC, pp. 9-15 (2000).

91. Landis, B., et al. “Modeling the Roadside Walking Environment: Pedestrian LOS,” *Transportation Research Record 1773*, Transportation Research Board, Washington, DC (2001).
92. Chu, X., and M. Baltes. *Pedestrian Mid-block Crossing Difficulty*, National Center for Transit Research, University of South Florida, Tampa, FL (2001).
93. Nadeir, J., and B. Raman, “Design Consideration in Simulating Interactive Virtual Pedestrian Environments.” Presented at the Transportation Research Board Annual Meeting, Washington, DC (2002).
94. United States Census, Ranking Tables for Population of Metropolitan Statistical Areas, http://www.census.gov/population/www/estimates/metrodef.html) (2004).
95. Davison, A., and D. Hinkley. *Bootstrap Methods and their Application*. Cambridge, UK: Cambridge University Press (1997).
96. Searle, S.R. *Linear Models for Unbalanced Data*. New York: Wiley (1987).
97. Agresti, A. *Categorical Data Analysis*, Second Edition, John Wiley & Sons, Hoboken, NJ (2002).
98. Furth, P., and T. Miller. “Service Reliability and Hidden Waiting Time: Insights from AVL Data,” *Transportation Research Record 1955,* Transportation Research Board, Washington, DC (2006).
99. Balcombe, R. (editor). “The demand for transport: a practical guide,” *Report TRL593,* TRL Limited, Wokingham, UK (2004).
100. Pratt, R. *TCRP Research Results Digest 61: Traveler Response to Transportation System Changes—An Interim Introduction to the Handbook,* Transportation Research Board, Washington, DC (2003).
101. Kittelson & Associates, Inc., et al. *TCRP A-23A Bus Rapid Transit Practitioners Guide, Final Draft* (2006).
102. St. Jacques, K., and H. Levinson. *TCRP Report 26: Operational Analysis of Bus Lanes on Arterials,* Transportation Research Board, National Research Council, Washington, DC (1997).
103. Newell, G. “Dispatching Policies for a Transportation Route,” *Transportation Science,* Vol. 5, pp. 91-105 (1971).
104. Mohring, H. “Optimization and Scale Economies in Urban Bus Transportation,” *American Economic Review,* Vol. 62, No. 40, pp.591-604 (1972).
105. Balcombe, R. (editor). “The demand for transport: a practical guide”, *Report TRL593*, TRL Limited, Wokingham, United Kingdom (2004a).
106. Balcombe, R. (editor). “The demand for transport: a practical guide”, *Report TRL593*, TRL Limited, Wokingham, United Kingdom, Table 8.9, non-London commuter values (2004b).
107. Turnquist, M. “A Model for Investigating the Effects of Service Frequency and Reliability on Bus Passenger Waiting Times,” *Transportation Research Record 663,* Transportation Research Board, National Research Council, Washington, DC (1978).
108. Outwater, M., and W. Charlton. “The San Francisco Model in Practice: Validation, Testing, and Application,” presented at the Innovations in Travel Modeling 2006 Conference, Austin, Texas (May 21-23, 2006).
109. Balcombe, R. (editor). “The demand for transport: a practical guide,” *Report TRL593*, TRL Limited, Wokingham, United Kingdom (2004).
110. *The Highway Capacity and Quality of Service Manual*, Transportation Research Board, National Research Council, Washington, DC (2000).
111. *2002 Quality/Level of Service Handbook*, Florida Department of Transportation, Office of the State Transportation Planner, Systems Planning Office, Tallahassee, FL, (http://www11.myflorida.com/planning/systems/sm/los/) (January 7, 2003).
112. Petritsch, T., et al. “Level-of-Service Model for Pedestrians at Signalized Intersections,” *Transportation Research Record 1939*, Transportation Research Board, Washington, DC (2005).
113. *The Highway Capacity and Quality of Service Manual*, Transportation Research Board, Washington, DC, pg. 18-7 (2000).

APPENDIX A

Subject Data Collection Forms

Circle the letter grade that most represents your perceived service.
A **= highest rating** ***F*** **= lowest rating**
Please view the entire video clip before selecting a rating.

Pedestrian Presentation

Clip Number	Perceived Service Rating					
Practice Clip #212	A	B	C	D	E	F
#201	A	B	C	D	E	F
#226	A	B	C	D	E	F
#225	A	B	C	D	E	F
#208	A	B	C	D	E	F
#219	A	B	C	D	E	F
#228	A	B	C	D	E	F
#211	A	B	C	D	E	F
#215	A	B	C	D	E	F
#229	A	B	C	D	E	F
#222	A	B	C	D	E	F

Circle the letter grade that most represents your perceived service.
***A* = highest rating** ***F* = lowest rating**
Please view the entire video clip before selecting a rating.

Bicycle Presentation

Clip Number	Perceived Service Rating					
Practice Clip #326	A	B	C	D	E	F
#319	A	B	C	D	E	F
#308	A	B	C	D	E	F
#306	A	B	C	D	E	F
#309	A	B	C	D	E	F
#320	A	B	C	D	E	F
#318	A	B	C	D	E	F
#304	A	B	C	D	E	F
#324	A	B	C	D	E	F
#321	A	B	C	D	E	F
#329	A	B	C	D	E	F

Circle the letter grade that most represents your perceived service.
***A* = highest rating** ***F* = lowest rating**
Please view the entire video clip before selecting a rating.

Automobile Presentation

Clip Number	Perceived Service Rating					
Practice Clip #5	A	B	C	D	E	F
#20	A	B	C	D	E	F
#56	A	B	C	D	E	F
#10	A	B	C	D	E	F
#51	A	B	C	D	E	F
#14	A	B	C	D	E	F
# 2	A	B	C	D	E	F
#62	A	B	C	D	E	F
#63	A	B	C	D	E	F
#52	A	B	C	D	E	F
#15	A	B	C	D	E	F

Please circle the choice which best describes your characteristics.

1. Your age group: **18-35 years of age** **36-60 years of age** **60 and up years of age** 2. Gender: **Male** **Female**

3. Number of vehicles in your household: **0** **1** **2** **3 or more** 4. Number of bicycles in your household: **0** **1** **2** **3 or more**

5. Employment status: **Employed** **Unemployed** **Homemaker** **Retired**

6. Your primary residence is: **A. Single-family detached home** **B. Apartment/duplex/townhouse/condominium** **C. Group quarters such as a college dormitory or independent living facility** **D. Other, please specify:** ________________

7. Do you rent or own your home? **A. Rent B. Own** 8. What is your primary residence/home zip code? ______________

9. If you are currently employed, what is your workplace zip code (or city of location): __________________________

10. How often do you walk more than two blocks a week for a non-recreational trip (for example, walk to work, walk to school, walk to a store)?
A. Never **B. Less than once a month** **C. About once a week** **D. More than once a week but not every day** **E. At least once a day**

11. How often do you walk more than two blocks a week for a recreational trip or for exercise ?
A. Never **B. Less than once a month** **C. About once a week** **D. More than once a week but not every day** **E. At least once a day**

12. How often do you use a bicycle for a non-recreational trip (for example, ride a bike to work, ride a bike to a store)?
A. Never **B. Less than once a month** **C. About once a week** **D. More than once a week but not every day** **E. At least once a day**

13. How often do you use a bicycle outside of a gym for a recreational trip or for exercise ?
A. Never **B. Less than once a month** **C. About once a week** **D. More than once a week but not every day** **E. At least once a day**

14. How often do you use transit (bus, subway, train)?
A. Never **B. Less than once a month** **C. About once a week** **D. More than once a week but not every day** **E. At least once a day**

15. How often do you use a car?
A. Never **B. Less than once a month** **C. About once a week** **D. More than once a week but not every day** **E. At least once a day**

16..What is your usual means of travel to work? **A. Auto, drive alone** **B. Auto, carpool** **C. Transit (bus, train, ferry or other)** **D. Walk** **E. Bike** **F. Other:** ________________________

APPENDIX B

Study Protocol

PROTOCOL:

1. There are no direct benefits to the participants. The study is likely to yield general information about driver perception of quality of service of roadways. We will use the drivers' appraisal of streets as depicted on video clips to understand driver perception. Currently, there is no recognized methodology that measures the quality of service provided by transportation facilities from the drivers' perspective. We will recruit participants in four representative locations in the US through personal contact and limited advertising.
2. We will ask participants to read and sign an informed consent sheet (a representative copy is attached, which will be replaced by the approved informed consent form when approved by the HSRB). Participants who elect to be paid will receive a $75 cash payment upon completion of the study. Participants will be paid through the grant. Payment is required to compensate for the inconvenience and time required to participate in the study. Student participants will receive course credit.
3. No minors will be involved. Participants will be at least 18 years of age.
4. Participants will view a series of video clips using a large screen projection system and an LCD projector. The test will be conducted in two parts. In part 1 of the study travelers will be prompted to rate their overall level of satisfaction with the facility on an A-F scale. After viewing all of the clips (total viewing time less than 120 minutes with 2-3 10 minute breaks) part 2 of the study will begin. Part 2 of the study is a focus group that will involve a portion (6-7 participants) of the participants. The purpose of part 2 is to learn more about specific features or conditions that relate to driver ratings of performance as portrayed in the video clips.
5. Each subject will be assigned a unique ID number. However, the information connecting a person's ID to their name will be stored in a separate file until data collection for that subject is completed. At that time, person-identifiable information will be discarded, as it will no longer be needed. Thus, no person-identifiable data will be maintained once data collection has been completed.
6. This research poses no more risk than that which would ordinarily be encountered in daily life. The expected benefit of this research is an increase of knowledge about the factors underlying driver satisfaction with the quality of service on urban arterials.
7. The rating forms will be secured at the George Mason University Department of Civil, Environmental, and Infrastructure Engineering (identified by subject id number and date), and will not be shown to individuals or agencies outside of the research team. The forms will be stored in a secure, locked private office and labeled by subject number, date and location. Participants' names will not be written on the forms. The data on the forms will be entered on a computer spreadsheet, but subjects' names will not be entered in the spreadsheet.
8. There is no need to misinform, or to not inform subjects about the true nature of the project.

Informed Consent Form

The purpose of this project is to obtain driver opinion about roadway conditions and features in a multimodal environment. In the study, you will be asked to watch several video clips. Upon the completion of each video clip, you will be given the opportunity to write down your rating of the clip. Once you are finished rating a clip, the next clip will be shown and the process will be repeated. After about one hour, we will take a break and questions will be entertained. After the break, we will resume watching clips and you will rate the clips. The project can benefit drivers indirectly by helping traffic engineers further understand the features and factors on roadways that are important to the driving public. There are no direct benefits to you; however, the project may help traffic engineers further understand the features and factors on roadways that are important to the driving public.

The entire sessions should not last longer than three hours. Upon completion of the clip ratings, you will be asked to turn in your rating sheets. We will then provide you with an honorarium. At that time, we will answer any questions you may have about the project.

Please note the following:

- Your participation is voluntary. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.
- You will be provided with a $75 honorarium in recognition of the value of your contribution to the study.
- All data collected in this study are confidential. All surveys will be discarded after the data analysis.

This study is being directed by Aimee Flannery of the Civil, Environmental, and Infrastructure Engineering Department at George Mason University. Dr. Flannery may be contacted by email at aflanner@gmu.edu or at 703-993-1738 should any question arise. You may also contact the George Mason University Office of Sponsored Programs at 703-993-2295 if you have any questions or comments regarding your rights as a participant in this research. The project has been reviewed according to the George Mason University procedures governing your participation in research. The Transportation Research Board is funding this study.

I have read this form and agree to participate in the study.

Consent Signature: ____ Date: _____________

Witness Signature: ____ Date: _____________

George Mason University
Human Subjects Review Board

Application for Human Subjects Research Review

For OSP Use Only *GMU*
Protocol No. ____________ Proposal No. ___________
Classified: ☐Exempt ___ ☐Non Exempt ☐Expedited
Signature Date

Federal Regulations and George Mason University policy require that all research involving humans as subjects be reviewed and approved by the University Human Subjects Review Board (HSRB). Any person, (GMU faculty member, staff member, student, or other person) wanting to engage in human subject research at or through George Mason University must receive written approval from the HSRB before conducting research. Human Subject is defined as a living individual about whom an investigator conducting research obtains a) data through intervention with the individual, or b) identifiable private information or records. Research is the systematic investigation, including research development, testing and evaluation, designed to develop or contribute to knowledge. Approval of this project by the HSRB only signifies that the procedures adequately protect the rights and welfare of the subjects and should not be taken to indicate University approval to conduct the research.

Please complete this cover page AND provide the Protocol information requested on the back of this form. Forward this form and all supporting documents to the Office of Sponsored Programs, Compliance Department, MS 4C6. **If you have any questions please feel free to contact the Compliance Department at 703-993-4121** .

Project Title: NCHRP 370 Phase II Study 1 Multimodal Urban Street Level of Service

Required Data	Principal Investigator	Co-Investigator/Student Researcher
Name	Aimee Flannery, Ph.D., P.E.	
Department	Civil, Environmental, and Infrastructure Engg	
Mail Stop	4A6	
Phone	3-1738	
E-mail	aflanner@gmu.edu	
Status	◀ Faculty/Staff ☐ Other __________________________	☐ Doctoral Dissertation ☐ Masters Thesis ☐ Class Project(Specify Grad or Under Grad)

I certify that the information provided for this project is correct and that no other procedures will be used in this protocol. I agree to conduct this research as described in the attached supporting documents. I will request and receive approval from the HSRB for changes prior to implementing these changes. I will comply with the HSRB policy for the conduct of ethical research. I will be responsible for ensuring that the work of my co-investigator(s) /student researcher(s) complies with this protocol.

Aimee Flannery

Principal Investigator Signature **4/07/06 Date**

ABSTRACT: The abstract must appear here. Use a separate sheet for continuation. Refer to the guidelines on the reverse side.[4]
The project's goal is to obtain driver opinions and perceptions of the quality of service on urban streets, defined here as signalized, multi-lane highways with cross-streets placed ½ to 1 mile apart. Drivers' perceptions of service can be useful to traffic engineers in the design and improvement of roadways and can be used to supplement the Highway Capacity Manual.

The information obtained in the project will provide the academic and practitioner with a better understanding of driver perceptions about roadway quality of service. The project proposes to ask licensed drivers to view video taped segments of urban streets and rate the quality of service on the streets presented on the video. The drivers will complete a short rating form for each segment shown. The video tapes will be projected on a large screen in a classroom setting. Approximately 140 drivers are required for this project. The subjects will be licensed drivers aged 18-65 years of age. The criterion for inclusion for the subjects is a valid driver's license and willingness to participate in the study. Drivers will be paid for their participation or receive class credit.

The proposed research will involve the following **(check all that apply):**

VULNERABLE POPULATION: __Fetuses/Abortuses/Embryos __Pregnant women __Prisoners __Minors __Mentally retarded/disabled __Emotionally disabled __Physically disabled __Psychology undergrad pool __Other:	PERSON IDENTIFIABLE DATA: __ Audio taping __ Video taping __ Data collected via email __ Data collected via internet __ Confidential electronic records __ Coded data linked to individuals __ Human biological materials	RESEARCH DESIGN: __ Questions on harm to self or others __ Questions on illegal behavior __ Deception __ Human/computer interaction __ Collection and/or analysis of secondary data OUTSIDE FUNDING: Source ____Transportation Research Board____________________________

Revised March 2005

ABSTRACT

1. Describe the aims and specific purposes of the research project and the proposed involvement of human participants.
2. Describe the characteristics of the intended sample (number of participants, age, sex, ethnic background, health status, etc).
3. Identify the criteria for inclusion or exclusion. Explain the rationale for the involvement of special classes of participants (children, prisoners, pregnant women, or any other vulnerable population.
4. Describe your relationship to the participants if any.

PROTOCOL—Involving Human Participation

1. If there are direct benefits to the participants, describe the direct benefits and also describe t he general knowledge that the study is likely to yield. If there are no direct benefits to the participants, state that there are no direct benefits to the participants and describe the general knowledge that the study is likely to yield.
2. Describe how participants will be recruited. Note that all advertisements for participants must be submitted for review for both exempt and non-exempt projects.
3. Describe your procedures for obtaining informed consent. Who will obtain consent and how will it be obtained. Describe how the researchers will ensure that subjects receive a copy of the consent document.
4. State whether subjects will be compensated for their participation, describe the form of compensation and the procedures for distribution, and explain why compensation is necessary.

   State whether the subjects will receive course credit for participating in the research. **If yes**, describe the nonresearch option for course credit for the students who decide not to participate in the research. The nonresearch option for course credit must not be more difficult than participation in the research. Information regarding compensation or course credit, should be outlined in the Participation section of the consent document.
5. If minors are involved, their active assent to the research activity is required as well as active consent from their parents/guardians. This includes minors from the Psychology Department Undergraduate Subject Pool. Your procedures should be appropriate to the age of the child and his/her level of maturity and judgment. Describe your procedures for obtaining active assent from minors and active consent from parents/guardians. Refer to the Guidelines for Informed Consent for additional requirements if minors from the Psychology Subject Pool are involved.

6. Describe what participants will be asked to do. Include an estimate of the time required to complete the procedures.
7. Describe how confidentiality will be maintained. If data will be collected electronically (e.g. by email or an internet web site), describe your procedures for limiting identifiers. Note that confidentiality may have to be limited if participants are asked questions on violence toward self or others or illegal behavior. Contact the Office of Sponsored Programs for assistance.
8. Describe in detail any potential physical, psychological, social, or legal risks to participants and why they are reasonable in relation to the anticipated benefits. Where appropriate, discuss provisions for ensuring medical or professional intervention in case participants experience adverse effects. Where appropriate, discuss provisions for monitoring data collection when participants' safety is at risk.
9. If participants will be audio-or video-taped, discuss provisions for the security and final disposition of the tapes. Refer to #2 of the Guidelines for Informed Consent.
10. If participants will be misinformed and/or uninformed about the true nature of the project, provide justification. Note that projects involving deception must not exceed minimal risk, cannot violate the rights and welfare of participants, must require the deception to accomplish the aims of the project, and must include a full debriefing. Refer to #8 of the Guidelines for Informed Consent.

INFORMED CONSENT: Provide appropriate Proposed Informed Consent document(s).
See Guidelines for Informed Consent and Model Informed Consent Document for additional information.

INSTRUMENTS: Submit a copy of each instrument/tool you will use and provide a brief description of its characteristics and development. Submit scripts if information and/or questions are conveyed verbally.

APPROVAL FROM COOPERATING INSTITUTION/ORGANIZATION:
If a cooperating institution/organization provides access to its patients/students/clients/ employees/etc. for participant recruitment or provides access to their records, submit written evidence of the institution/organization human subjects approval of the project.

Note: If research involves use of existing records, please see guidelines on following page.
Revised March 2005

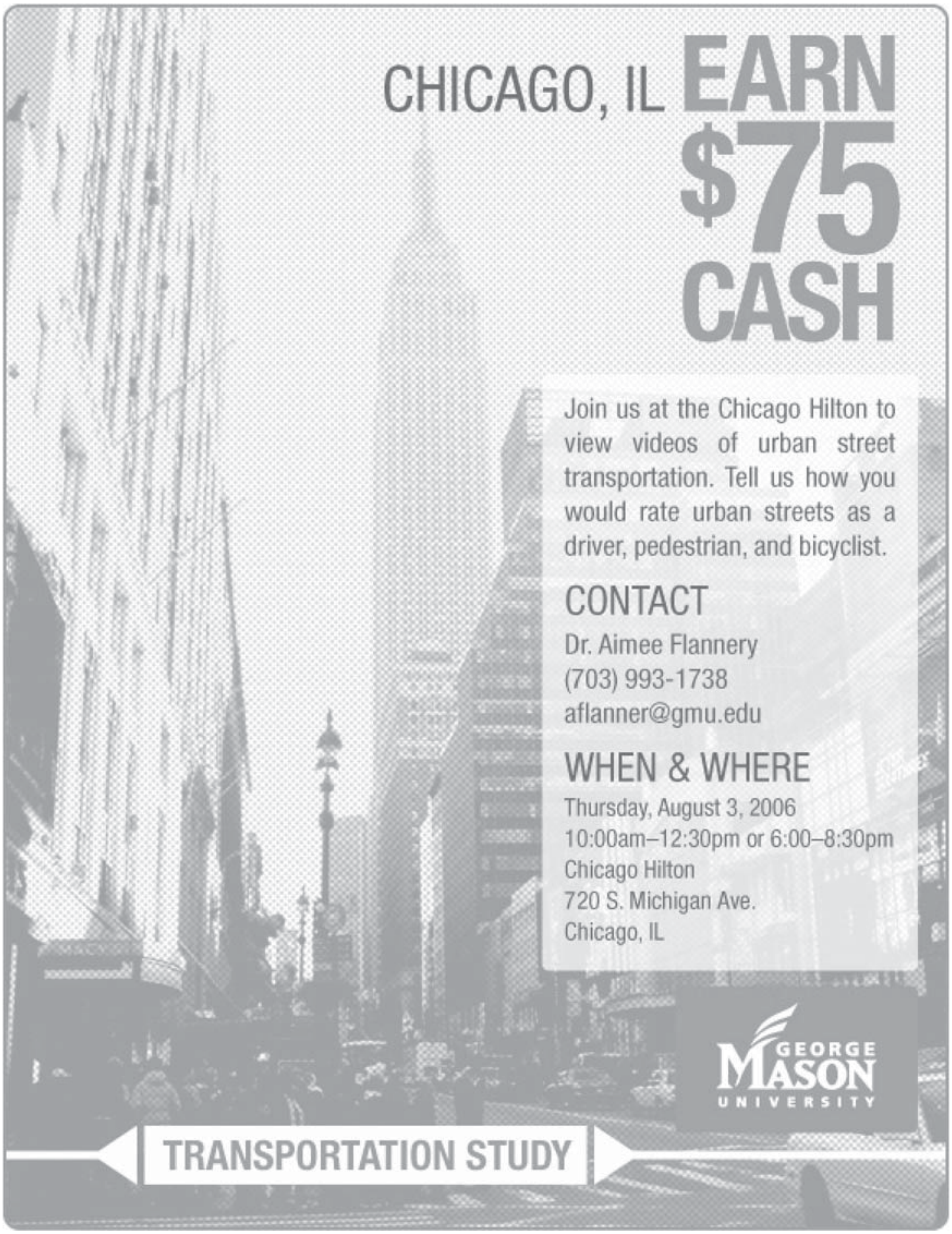
PROTOCOL—Involving Existing Records

(For the study of existing data sets, documents, pathological specimens, or diagnostic specimens.)

1. Describe your data set.
2. Provide written permission from the custodian of the data giving you access for research purposes at George Mason University if the data set is not publicly available.
3. Describe how you will maintain confidentiality if the data set contains person identifiable data.
4. Describe what you are extracting from the data set.

APPENDIX C

Example Recruitment Flyer/Poster



Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation