MULTIMODAL LEVEL OF SERVICE FOR SUBURBAN AREAS: MEASUREMENT METHODOLOGY AND CASE STUDIES

by

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ABSTRACT

Level of service is a way of measuring how well a transportation facility serves its users. For the driver of a motor vehicle, level of service is most dependent on the congestion and delay characteristics of a roadway. However, for other transportation users—such as pedestrians, bicyclists, and transit riders—factors outside of congestion are often more important to the level of service that a facility provides. Multimodal level of service measurement methodologies, which focus largely on non-automobile modes, have garnered increased attention and research efforts within the past few decades, and a number of qualitative and quantitative methodologies are now available. These multimodal level of service projects and methodologies are part of a larger movement in transportation planning and engineering to build a more multimodal, less car-dependent transportation system, particularly in the United States.

This thesis expands on recent multimodal level of service research by developing and testing a new multimodal level of service methodology specifically tailored to suburban areas. Through literature research, public participation, and field and remote data collection, the new multimodal LOS methodology was tested in two cases studies conducted in Newark, Delaware and Elkton, Maryland. The methodology resulting from this project presents a valid and detail-level measurement tool for multimodal level of service.

Chapter 1

INTRODUCTION

1.1 Transportation Planning Practice and the Rise of Multimodal Planning

Over the past century, the fields of transportation planning and engineering have grown in importance along with the expansion of the U.S. population and its demand for greater mobility. With the subsequent advent of the private automobile and the explosion of the American automobile industry as a major contributor to economic growth, transportation planning and engineering have focused on—and been driven by—the perceived need to accommodate the automobile. As a result of this confluence of social, economic, and technological forces, the U.S. transportation system has pursued the efficient movement of people and goods by prioritizing motor vehicles (including personal automobiles as well as freight trucks). This preference for automobiles has created a culture of car-dependency in the U.S. with well-documented negative consequences for land use patterns, the natural environment, public health, social equity, and economic competitiveness (Newman 1996).

The past couple of decades have seen increasing interest and effort from transportation planners and engineers to move away from car-dependency and create more multimodal transportation systems and communities that accommodate travel mode choices for people of all ages, abilities, and economic status. Some of this push for more emphasis on planning for pedestrians, bicyclists, and transit services has come from advocacy organizations and alternative transportation movements. The following groups and movements that advocate for multimodal transportation systems and land-use reform have been formed within the last twenty years: The Pedestrian and Bicycle Information Center, The Congress for New Urbanism, the National Complete Streets Coalition, Transportation for America, and Smart Growth America. Additional impetus for increasing consideration of all modes in transportation planning and engineering has come from local, state, and federal transportation funding programs. At the federal level, the significant shift to a more multimodal way of regulating and funding transportation systems did not occur until relatively recently, with the passage of the Intermodal Surface Transportation Efficiency Act of 1991 (Federal Highway Administration, "Federal-Aid Highway Program Funding"). Since then, an increasing number of programs and planning activities that emphasize multimodal transportation options—such as "Transportation Enhancements" and "Safe Routes to School"—have been funded (and often required) at all levels of government.

One very specific way in which the automobile-dominated processes of transportation planning and engineering are being broadened is through the development of multimodal level of service analysis methodologies. Level of service (LOS) is a key tool used by transportation planners and engineers to assess the performance of current roadways and plan for the construction or expansion of new roadway facilities. Motor vehicle LOS has a long history of use in the U.S. and is essentially a measure of congestion and delay. LOS measurements for the pedestrian, bicycle, and transit modes, however, have not historically been factored into the transportation planning process. This is starting to change as transportation agencies begin to require the consideration and accommodation of all modes in transportation projects and planning documents.

The consideration of all modes (and all possible users) in transportation planning and projects is captured in the term and movement called "complete streets." According to the National Complete Streets Coalition, complete streets "…are designed and operated to enable safe access for all users. Pedestrians, bicyclists, motorists and transit riders of all ages and abilities must be able to safely move along and across a complete street." Many jurisdictions and organizations—including the State of Delaware, WILMAPCO, and the Maryland Department of Transportation—have put policies in place to ensure the development of complete streets through planning and engineering practices (State of Delaware Department of Transportation 2009). While multimodal LOS analysis is not an official component of complete streets concepts or policies, the goal of integrating multimodal LOS into transportation planning and engineering processes is very much in line with the complete streets vision—to ensure the accommodation and safety of all road users.

Theoretical and empirical research into the concept of LOS for non-automobile transportation modes has increased along with the rise in multimodal planning and complete streets initiatives. Multimodal LOS is now a vibrant transportation planning topic throughout the country, and methods of using and implementing multimodal LOS are even being considered at the federal policy level. This thesis document adds to the national multimodal LOS discussion by developing and testing a new measurement methodology tailored to suburban regions similar to New Castle County, Delaware.

1.2 Multimodal Level of Service Project

In the fall of 2009, the Wilmington Area Planning Council (WILMAPCO) partnered with the University of Delaware's Institute for Public Administration to explore options for analyzing multimodal LOS in the Wilmington, Delaware region. The project team for this task consisted of staff from WILMAPCO as well as graduate research assistants from the Institute for Public Administration. This paper documents the process of this multimodal level of service project as well as follow-up research and data collection pursued by the author.

The project process included a literature review of multimodal LOS methodologies and theories (Chapter 2), development of a multimodal LOS methodology for the Wilmington, Delaware region (Chapter 3), and implementation of this multimodal LOS methodology in two different test locations (Chapter 4). The methodology was first applied to one roadway in Newark, Delaware, where both WILMAPCO and the University of Delaware are located. This roadway was chosen because of its proximity to the project team's places of work as well as the characteristics of the roadway itself. After some revisions, the methodology was also applied to a sample of roadways in Elkton, Maryland. Elkton is the county seat of Cecil County, MD with a population of about 15,000 ("Town of Elkton" 2011). Elkton was chosen to support a bicycle study being performed by WILMAPCO.

The remaining chapters of this paper detail each stage of the multimodal level of service project, including the results of implementing the methodology on sample roadways. The conclusion chapter reflects on the lessons learned during the project process, areas for further research and refinement, and the place of this project in relation to larger transportation planning issues.

Note: Unless otherwise cited, all pictures, figures, and maps were created by the author. All index item excerpts in Chapter 3 are drawn from the indexes in Appendix C.

Chapter 2

REVIEW OF LITERATURE

2.1 Introduction

Transportation facilities and services are intended to perform the essential function of moving people and goods in a safe and efficient manner. An important part of planning, engineering, and maintaining transportation facilities is the ability to evaluate the degree to which these facilities are achieving their functions and purposes. While there are many ways to evaluate transportation facilities and services, the focus of this paper is on the quality and "level" of service provided by multimodal transportation facilities. Quality of service is a concept based on user perceptions of how well a transportation facility or service operates (Florida Department of Transportation, 2009, p. 12). This kind of measurement differs from other methods of evaluating transportation facilities that may be based on perceptions of transit owners, freight operators, departments of transportation, or governmental entities. There are four basic dimensions of mobility that a transportation facility provides: (1) Quality of travel; (2) Quantity of travel; (3) Accessibility; and (4) Capacity utilization (FDOT, 2009, p. 12). Quality of service measures focus primarily on the *quality* of travel dimension, which is evaluated from a *user perspective*. Transportation agencies or government officials, on the other hand, may focus primarily on quantity of travel and capacity utilization dimensions. Level of service

(LOS) measurements are a subset of quality of service that quantify user perceptions into discreet categories. Most commonly, these LOS measurements are numerically divided into six scoring categories represented by the letter grades A through F, with A being the "best" and F being the "worst." In other words, level of service quantifies the quality of service dimension of mobility.

Multimodal LOS aims to measure LOS scores for the four major groups of road users: motorists, bicyclists, pedestrians, and transit riders. An important consideration when looking at multimodal LOS, which will be demonstrated throughout this paper, is that the factors affecting level of service are different for each mode of transportation, even within the same roadway environment. A single roadway can have four distinct LOS scores for the various modes, and these scores may differ greatly between each mode. For example, a roadway that provides a good LOS for automobile drivers (fast speeds, minimal intersection delays) would probably be a dangerous environment (poor LOS) for pedestrians. This is in part because vehicle speeds are a key factor in pedestrian safety, as evidenced by the statistic that pedestrian crash fatality rates are about five percent at a vehicle speed of 20 mph, while the fatality rate drastically rises to forty percent at a vehicle speed of 30 mph (see Figure 2.1) (Leaf and Preusser 1999, p. 3.1).

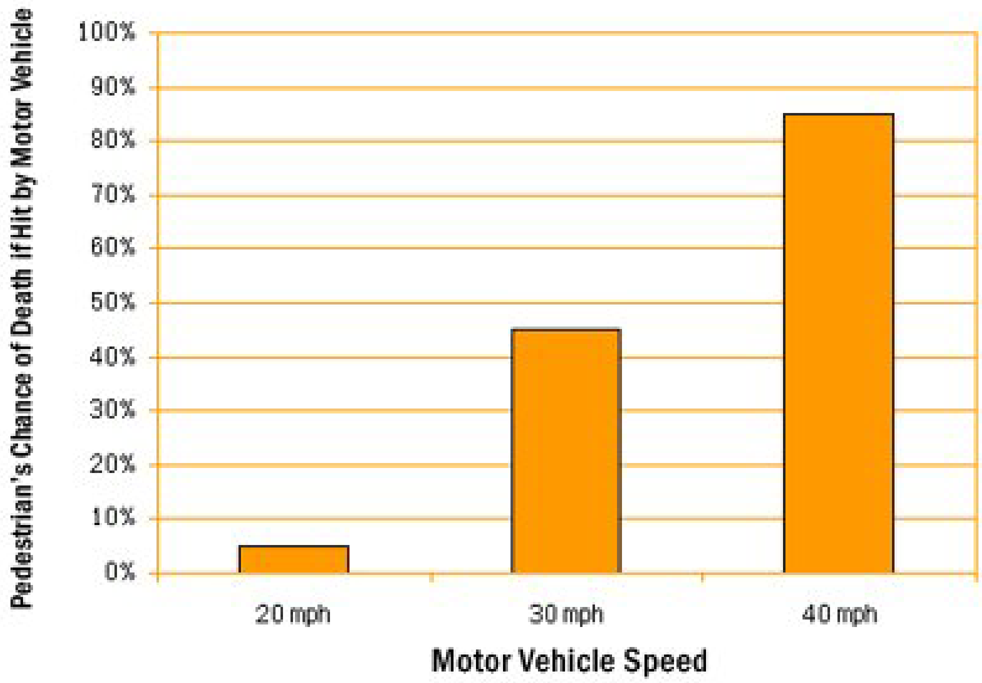


Figure 2.1 Pedestrian fatalities based on speed of vehicle. (n.d.). Retrieved from http://www.walkinginfo.org/problems/problems-motorists.cfm

It is important to note, however, that comparing LOS scores between modes, for planning and engineering purposes, is not advisable. For automobile LOS, a score of D or E is sometimes considered acceptable, while a bicycle or pedestrian LOS score of D or E would mean that the roadway is not suitable and is unsafe for pedestrians and cyclists. LOS A for bicyclists is considered a good thing in urban areas because it means that facilities are present and the bicycling environment is relatively safe. LOS A for motor vehicles in an urban area, however, is not considered good because this represents essentially constant free-flow conditions on the roadway. This would indicate that the capacity of the road is much larger than the traffic volume, representing a waste of valuable space and resources.

For multimodal LOS there is also the problem of public perception of LOS grades. Guttenplan, Landis, Crider, and McLeod (2001) explain that the general public, accustomed to school letter grades, views a score of D as barely passing, whereas transportation engineers know that a LOS score of D for the automobile mode in an urban area is often a condition to strive for (p. 158). This difference is due to the fact that the concepts and variables that go into LOS measurement differ between each mode. In general, however, one could say that transportation planners and engineers would want to aim for a LOS score of A or B for bicycle, pedestrian, and transit systems in urban areas, whereas roadways should be planned for an automobile LOS of C or lower in urban areas.

A more detailed explanation of level of service concepts and methodologies for each of the four modes is offered in the following sections. This review of literature, and the LOS methodology development described in Chapter 3, focuses only on the immediate roadway environment. Therefore off-street facilities such as separated bicycle and pedestrian paths or commuter rail services that do not share the roadway environment are not evaluated in this paper.

2.2 Highway Capacity Manual, 2000

The *Highway Capacity Manual* (2000) is a good starting point for discussing the development and implementation of LOS measurements and methodologies. The *Highway Capacity Manual* (HCM) defines LOS as "…a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience…Safety is not included in the measures that establish service levels" (2000, pp. 2.2 - 2.3). It is important to note that safety is not considered in the HCM's methodologies since, especially for pedestrians and bicyclists, the perception of safety is a key contributor to users' evaluation of quality of service. The HCM provides detailed conceptual and methodological descriptions of LOS for motor vehicles, pedestrians, bicyclists, and transit, and these are reviewed briefly below.

Motor vehicle LOS is essentially a function of driver delay along road segments and at intersections. The simplest calculation of motor vehicle LOS on an urban street involves a comparison of typical free flow speed to actual average travel speed, based on running time and intersection control delay (HCM 2000, p. 15.2). Factors that affect motor vehicle LOS include congestion delay (when volume exceeds capacity), intersection delay, and the amount of flow interruptions such as driveways and side streets. In contrast, the HCM's methodology for pedestrian LOS is based on the basic concept of space per pedestrian on sidewalks, walkways, and intersection queuing areas (pp. 18.4-18.10). The other major factor in pedestrian LOS is delay at signalized intersections (p. 18.7). While the HCM provides many different LOS calculation potentials for differing types of facilities and situations, it is safe to say that intersection delay and facility density are the two major factors considered in the HCM pedestrian LOS methodology.

The *Highway Capacity Manual* (2000) provides bicycle LOS methodologies for bicycle-only paths, shared-use off-street paths, and on-street bicycle lanes. For on-street bicycle lanes and facilities, the HCM evaluates bicycle LOS in terms of the delay experienced by bicyclists along the roadway and at signalized intersections, which is very similar to the automobile LOS methodology (p. 19.5). The HCM also provides methodologies for calculating transit LOS based on vehicle capacity, person capacity, and travel speeds for on-street transit services (p. 27.1). Four service measures are used to evaluate transit LOS including: service frequency, hours of service, passenger loads, and reliability (p. 27.2). The transit quality and level of service concepts addressed in the HCM are discussed in more detail in the *Transit Capacity and Quality of Service Manual* (2003), which is addressed later in the transit section of this paper.

The LOS and capacity concepts defined in the HCM are generally the nationally accepted standards for evaluating roadways and other transportation facilities. While the motor vehicle LOS methodology has been heavily used by transportation planners and engineers and is arguably applicable to the majority of roadways throughout the United States, the pedestrian and bicycle LOS methods from the HCM do not adequately address the multitude of factors that affect pedestrians' and bicyclists' experiences in the roadway environment. Guttenplan, Landis, Crider, and McLeod (2001) have listed several reasons why the HCM bicycle and pedestrian methodologies are inadequate:

> Existing measures…for the bicycling or walking environment, are the degree of discomfort to the user due to crowding of a facility. Unfortunately, this measure of crowding applies only to a fraction of the collector and arterial network in U.S. metropolitan areas…Because the HCM is focused on individual modes, it does not consider the effects of motorized vehicles on pedestrians and bicyclists. (p. 151)

The fact that the HCM does not consider the effects of interactions between motor vehicles, bicyclists, and pedestrians is a major shortcoming. While the HCM methods measure density and delay experienced by bicyclists and pedestrians, a more appropriate measure for many locations throughout the United States would be the simple recognition of whether or not a facility for the mode is provided. In suburban and rural areas especially, the safety of walking or cycling is more of a concern for potential users than the number of other users or delay time at intersections.

For these reasons many researchers have undertaken a reevaluation of LOS for all modes of transportation. What follows is an exploration of a number of these alternative LOS methodologies. It should be noted here that this review of LOS literature is limited to those methodologies that define themselves as measuring "level of service." Though somewhat similar, research and measurement methodologies that address bicycle or pedestrian "friendliness" or transit "suitability," for example, are not addressed. The rationale for this is that the LOS concept is fairly well-established as a quantitative measure represented by letter grades A through F. In the multimodal context of this paper, it is important to establish a baseline definition of LOS so that different methodologies and modes can be compared to each other to some extent.

2.3 Pedestrian Level of Service

Pedestrian LOS measurements and methodologies can be conceptualized, generally, as attempts to qualify and quantify the conditions that contribute to a person's safety, comfort, and convenience when walking. Some pedestrian LOS literature addresses the experiences of pedestrians on off-road paths such as multi-use trails, walking paths within parks, or hiking trails. This paper addresses only pedestrian LOS as it relates to the "roadside" walking environment, which includes only sidewalks or other paths within a particular road's right-of-way. This focus is important for analyses of multimodal LOS because multimodal evaluation relies on consideration of the interaction between several modes of road users. This interaction would not occur on off-road paths where motorized vehicles are not present, and thus only roadside facilities are considered in this review.

Several researchers have contributed to defining and measuring pedestrian LOS. Almost all methodologies follow a general three-step process: (1) Determine the factors of the road and roadside environment which affect pedestrians; (2) Determine the relative importance of each of these factors; and (3) Assign numerical values to each factor that will sum to a total pedestrian LOS score. In order to examine the literature in detail it is helpful to divide the various methodologies into qualitative models and mathematical models. While all pedestrian LOS methodologies will involve some sort of quantification of variables, the distinction between qualitative and mathematical models comes down to the way in which the models are originally quantified or verified. Thus, for the purposes of this paper, mathematical models include those LOS methodologies that use statistical calibration to calculate the contribution of each factor to the entire LOS score whereas qualitative models do not.

2.3.1 Qualitative Models

Linda B. Dixon (1996) provides an in-depth, index-based qualitative pedestrian LOS methodology, as well as a similar methodology for bicycle LOS. Dixon's methodology was developed for the City of Gainesville, Florida's Congestion Management System and is based on previous pedestrian and bicycle compatibility research, a pilot test on twelve roadways in Gainesville, and meetings with local transportation planners and engineers (p. 8). Dixon's (1996) methodology is intended for facility-wide analysis, includes evaluation of road segments as well as intersections, and is most applicable to urban and suburban arterial and collector roadways (p. 1). Because this methodology was developed with an emphasis on congestion management, one of the goals of evaluating pedestrian and bicycle LOS was to increase the amount of non-motorized traffic on Gainesville's streets, thus reducing motorized congestion. Dixon points out that "…the methodology hypothesizes that there is a critical mass of variables that must be present to attract nonmotorized trips" (1996, p. 1). Thus Dixon's methodology aims to identify all of the factors whose presence would be necessary to attract non-motorized trips along the roadway of interest.

Dixon's (1996) pedestrian LOS index includes the following factors that should be evaluated for each segment of a facility: (1) Presence of pedestrian facilities (including sidewalk width and continuity); (2) Conflicts to pedestrian through-movement (including driveways and side streets per mile, crossing width at intersections, and vehicular turning movements at intersections); (3) Presence of pedestrian amenities such as buffer strips, benches, and street trees; (4) The automobile LOS for the segment; (5) Maintenance of the pedestrian facility; and (6) Support for multimodal connections through transit availability (table 1, p. 2). In Dixon's methodology, each category of variables listed above is worth a certain amount of points. In order to obtain a pedestrian LOS score for a roadway, the facility is rated on each of these variables, given a score for that category, and then the total score is converted to letter grades A through F based on the ranges provided by Dixon. The table and point values provided by Dixon are shown in Figure 2.2

PEDESTRIAN		
CATEGORY	CRITERION	POINTS
PEDESTRIAN FACILITY PROVIDED (Max Value = 10)	Not Continuous or Non-existent	0
	Continuous on One Side	4
	Continuous on Both Sides	6
	Min. 1.53m (5') Wide & Barrier Free	2
	Sidewalk Width >1.53m (5')	1
	Off-Street / Parallel Alternative Facility	1
CONFLICTS (Max Value = 4)	Driveways & Sidestreets	1
	Ped Signal Delay 40 Sec. or Less	0.5
	Reduced Turn Conflict Implementation	0.5
	Crossing Width 18.3m (60') or Less	0.5
	Posted Speed	0.5
	Medians Present	1
AMENITIES (Max Value = 2)	Buffer Not Less Than 1m (3.5')	1
	Benches or Pedestrian Scale Lighting	0.5
	Shade Trees	0.5
MOTOR VEHICLE LOS (Max Value = 2)	LOS = E, F, OR 6 or More Travel Lanes	0
	LOS = D and < 6 Travel Lanes	1
	LOS = A, B, C, and < 6 Travel Lanes	2
MAINTENANCE (Max Value = 2)	Major or Frequent Problems	-1
	Minor or Infrequent Problems	0
	No Problems	2
TDM / MULTI-MODAL (Max Value = 1)	No Support	0
	Support Exists	1
CALCULATIONS	Segment Score [1]	21
	Segment Weight [2]	1
	Adjusted Segment Score [3]	21
	Corridor Score [4]	21 = LOS A

[1] Segment Score = sum of points in the six categories
[2] Segment Weight = segment length / corridor length
[3] Adjusted Segment Score = Segment Score x Segment Weight
[4] Corridor Score = sum of the Adjusted Segment Scores in the corridor

Figure 2.2 Dixon (1996) pedestrian LOS index. Source: Dixon, L.B. (1996). Bicycle and pedestrian level-of-service performance measures and standards for congestion management systems. *Transportation Research Record 1538*, Washington, DC: Transportation Research Board, p. 2.

Nicole Gallin (2001) has developed a more subjective LOS index based on walking conditions and facilities in Western Australia. Gallin's methodology was developed through an iterative process of walkability research and meetings with key stakeholders. Gallin's study identifies the definition of pedestrian LOS as:

> …an overall measure of walking conditions on a route, path or facility. This is directly linked to factors that affect pedestrian mobility, comfort and safety. It reflects the pedestrians' perceptions of the degree to which the facility is pedestrian friendly. (2001, p. 121)

This particular methodology is applicable to the roadside environment as well as off-road paths and walkways, which introduces some factors into the index that are not particularly well-suited to roadside walking facilities (such as "mix of path users" which is intended to capture conflicts between other pedestrians and bicycles on the same path) (p. 121). Gallin's research process resulted in the identification of eleven factors that affect pedestrian LOS. Each factor is weighted, then summed to a total LOS score. Gallin's factors include: (1) Path width; (2) Surface quality; (3) Obstructions (permanent or temporary); (4) Crossing opportunities; (5) Support facilities (such as benches and signage); (6) Connectivity; (7) Path environment (surrounding area, including distance from roadway); (8) Potential for vehicle conflict; (9) Pedestrian volume; (10) Mix of path users, and (11) Personal security (2001, pp. 121-122).

The evaluation process for Gallin's (2001) index requires a combination of remote research and fieldwork in order to gather the pertinent data. Though some of Gallin's factors can be measured numerically, such as path width and pedestrian volume, the majority of them are highly subjective. For example, the connectivity factor is intended to be judged by the researcher from street maps, and the suggested measurement methodology for the personal security factor is to walk the path of interest at night and provide a rating based on opinion (p. 123). While there may be no other more objective option for measuring something like personal security, the connectivity measure can indeed be measured mathematically using a type of connectivity index. For example, Ewing (1996) defines the connectivity index as the ratio of street links to street nodes (p. 57). The subjectivity of some measures proposed by Gallin would introduce inconsistency in the methodology when applied by different researchers. Each of the eleven factors on Gallin's index is weighted on a scale from one to five, and like Dixon's (1996) index, discreet possible point categories are given for each possible situation (p. 125). The final pedestrian LOS score for walking paths is calculated by multiplying the score for each factor by the weighting number and summing this result for all eleven factors. The score is then translated into letter grades A through E (instead of A through F). Gallin's pedestrian LOS index and scoring table are shown in Figure 2.3.

Category	Factor	Weight	0 points	1 point	2 points	3 points	4 points
Design Factors	Path Width	4	No pedestrian path	0-1m	1.1 - 1.5m	1.6 - 2.0m	more than 2m wide
(Physical Characteristics)	Surface Quality	5	unsealed and/or many cracks/bumps, ie very poor quality	poor quality	moderate quality, i.e. some cracks/bumps etc.	reasonable quality, ie acceptable standard	excellent quality (continuous surface with very few bumps/cracks etc)
	Obstructions	3	more that 21 obstructions per km	between 11 and 20 obstructions per km	between 5 and 10 obstructions per km	between 1 and 4 obstructions per km	no obstructions
	Crossing Opportunities	4	none provided, difficult to cross	some provided but poorly located	some provided and are reasonably well located but more are needed	adequate crossing facilities are provided and are reasonably well located OR none are provided as they are unnecessary	dedicated pedestrian crossing facilities are provided at adequate frequency
	Support Facilities	2	non existent	few provided and poorly located	few provided and reasonably well located	several provided and well located OR absent but unnecessary	many provided and well located
Location Factors	Connectivity	4	non existent	poor	reasonable	good	excellent
	Path Environment	2	unpleasant environment, close to vehicular traffic	poor environment, may be within 1m of kerb	acceptable environment, between 1 and 2m of kerb	reasonable environment, between 2 and 3m from kerb	pleasant environment, pedestrians more than 3m from kerb
	Potential for Vehicle Conflict	3	severe, more than 25 conflict points per kilometre	poor situation, between 16 and 25 conflict points per km	moderate, ie 10 to 15 potential vehicle conflict points per km	reasonable, 1 to 10 or less conflict points per km	no vehicle conflict opportunities
User Factors	Pedestrian Volume	3	More than 350 per day	226 to 350 per day	151 to 225 per day	81 to 150 per day	Less than 80 per day
	Mix of Path Users	4	majority of path users are non-pedestrians	approx 51% to 70% of path users are non-pedestrians	between 21% and 50% non-pedestrian path users	less than 20% non-pedestrians	pedestrians only
	Personal Security	4	unsafe	poor	reasonable	good	excellent security provided

Figure 2.3 Gallin (2001) pedestrian LOS index. Source: Gallin, N. (2001). Quantifying pedestrian friendliness--Guidelines for assessing pedestrian level of service. ***Australia: Walking the 21st Century,*** **p. 125.**

2.3.2 Mathematical Models

Landis, Vattikuti, Ottenberg, McLeod, and Guttenplan (2001) developed a pedestrian LOS methodology using participant responses and statistical calibration techniques. The methodology is first based on the observations of volunteers who walked a pre-determined urban walking course during an event called “Fun Walk for Science” (p. 83). The observations of the participants were then statistically calibrated to the traffic and roadside conditions present along the walking course, resulting in a mathematical model. The authors describe the study’s overall methodology:

> The Model was developed through a stepwise multi-variable regression analysis of 1250 observations from an event that placed 75 people walking on a roadway course in the Pensacola metropolitan area in Florida. The Pedestrian LOS Model incorporates the statistically significant roadway and traffic variables that describe pedestrians’ perception of safety or comfort in the roadway environment between intersections. (2001, p. 82)

One key point about the Landis et al. (2001) model is that it is intended to evaluate LOS for road segments between intersections only. This model is one piece of a pedestrian LOS puzzle that includes a separate intersection LOS model. When the intersection and segment models are used together, they can be applied at the facility level. Another key feature of this model is that it can be used to evaluate roadways with or without pedestrian facilities present, which is an improvement over many previous attempts at pedestrian LOS calculation (2001, p. 83).

After calibrating participants’ observations to real-world conditions, Landis et al. (2001) developed a model with the following relevant variables: (1) Width of outside lane; (2) Width of shoulder or bike lane; (3) Presence of on-street parking; (4) Presence and width of buffer between edge of pavement and sidewalk; (5) Presence and width of sidewalk; (6) Average traffic during a fifteen-minute period; (7)

Total number of through lanes; and (8) Average running speed of motor vehicle traffic (p. 85). This study found that the presence of sidewalk facilities and their lateral separation from motorized traffic are the most important factors affecting pedestrians' perception of comfort (p. 86). Pedestrians' perceived comfort and safety as a result of separation from traffic can be impacted by the width of the buffer between pedestrian facilities and traffic (such as planting strips, parked cars, or bicycle lanes) as well as the frequency of the buffering factors (such as the number of street trees or the occupancy rate of on-street parking spaces) (See Figure 2.4). This pedestrian LOS model equation and factor descriptions are shown in Figure 2.5.

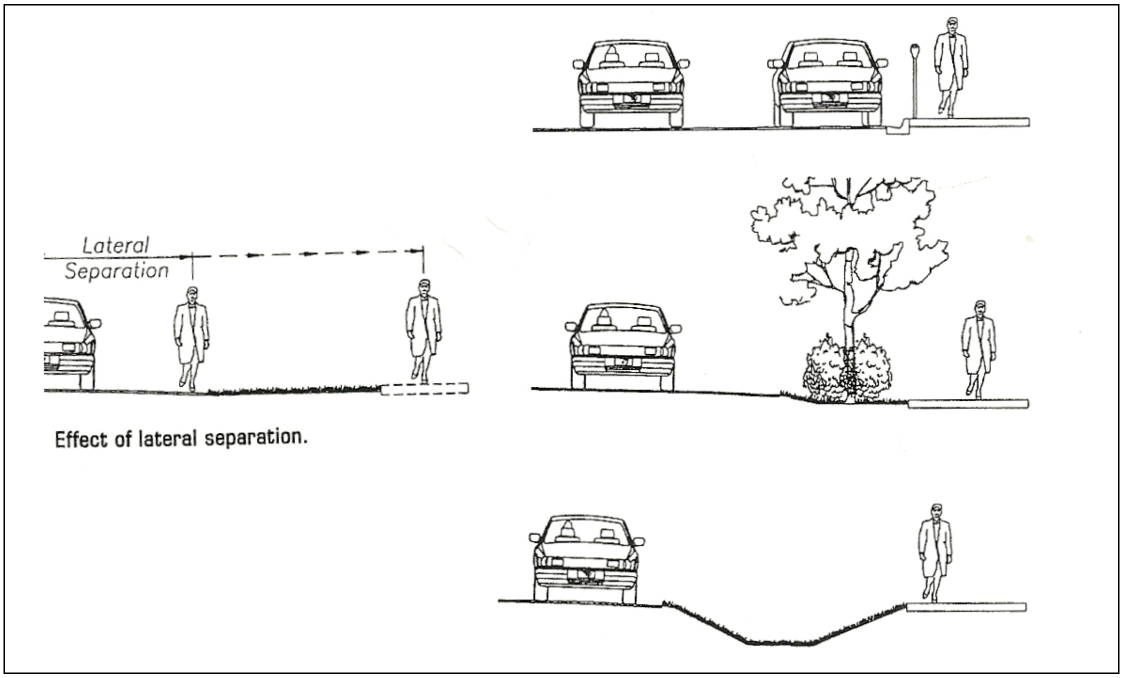


Figure 2.4 Lateral separation between pedestrians and motor vehicles. Source: Landis, B.W., Vattikuti, V.R., Ottenberg, R.M., McLeod, D.S., & Guttenplan, M. (2001). Modeling the roadside walking environment: Pedestrian level of service. ***Transportation Research Record 1773.*** **Washington, DC: Transportation Research Board, pp. 86-87.**

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

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),
W_s = width of sidewalk (feet),
Vol_{15} = average traffic during a 15-min period,
L = total number of (through) lanes (for road or street),
SPD = average running speed of motor vehicle traffic (mph), and
f_{sw} = sidewalk presence coefficient

$$= 6 - 0.3W_s. \quad (3)$$

Figure 2.5 Landis et al. (2001) pedestrian segment LOS model. Source: Landis, B.W., Vattikuti, V.R., Ottenberg, R.M., McLeod, D.S., & Guttenplan, M. (2001). Modeling the roadside walking environment: Pedestrian level of service. ***Transportation Research Record 1773.*** **Washington, DC: Transportation Research Board, p. 85.**

Jensen (2007) developed a pedestrian LOS model (in addition to a bicycle model discussed later) based on a number of studies performed in the United States, yet his model is particularly applicable to the Danish transportation system (p. 43). Similar to Landis et al. (2001), Jensen's model development involved pedestrian responses to specific walking conditions. Rather than a real-time walking course evaluation, however, Jensen's participants viewed video simulations of particular walking environments, which were produced by the researcher videotaping while he walked the courses (2007, p. 43). The walking environments represented in Jensen's study include thirty-eight urban and eighteen rural roadway segments, all in the vicinity of Copenhagen.

Using the responses of over 100 participants who watched the videos, along with data regarding traffic and roadway/walking path conditions, Jensen developed a pedestrian LOS model through a cumulative logit model and stepwise regression (2007, p. 48). Jensen's pedestrian LOS model includes seventeen total factors. The variables found to have the greatest effect on pedestrian satisfaction are the type and width of the walking area as well as the distance between the walking path and motor vehicles in the nearest drive lane, otherwise known as lateral separation (2007, pp. 48-49). The prevalence of these particular factors is strikingly similar to the most important factors identified by Landis et al. (2001). One notable difference between this Danish model and the models developed in the United States is the presence of a variable related to the volume of other pedestrians and bicyclists in the Danish model (p. 48). It is likely that this difference is due to the fact that pedestrian and bicycle crowding is more common in Denmark than in the U.S., where pedestrian and bicycle travel is much less common. The full equation and descriptions of Jensen's pedestrian LOS model are shown in Figure 2.6.

$$\mathrm{logit}(p) = \alpha \begin{bmatrix} \text{very satisfied} = -2.8526 \\ \text{moderately satisfied} = -1.2477 \\ \text{a little satisfied} = -0.0646 \\ \text{a little dissatisfied} = 0.8758 \\ \text{moderately dissatisfied} = 2.2543 \end{bmatrix} + \mathrm{WA} \begin{bmatrix} \text{sidewalk-concrete flags} = 3.5486 \\ \text{sidewalk-asphalt} = 1.9149 \\ \text{bicycle path/track} = 1.0124 \\ \text{bike lane/paved shoulder} = -2.8293 \\ \text{driving lane} = -3.6464 \end{bmatrix} + \mathrm{AREA} \begin{bmatrix} \text{residential} = 0.4871 \\ \text{shopping} = 0.5385 \\ \text{mixed} = -1.6349 \\ \text{rural fields} = 1.2380 \\ \text{rural forest} = 0.5122 \end{bmatrix}$$

$$-0.002476 \cdot \mathrm{MOT} + 0.0000003364 \cdot \mathrm{MOT}^2 - 0.0303 \cdot \mathrm{SPEED} + 0.00002211 \cdot \mathrm{SPEED} \cdot \mathrm{MOT} - 0.005432 \cdot \mathrm{PED}$$
$$+ 0.000005062 \cdot \mathrm{PED}^2 - 0.003772 \cdot \mathrm{BIKE} + 0.000003111 \cdot \mathrm{BIKE}^2 + 0.4408 \cdot \mathrm{BUF} - 0.0365 \cdot \mathrm{BUF}^2 - 0.05286 \cdot \mathrm{PARK}$$
$$+ 1.0180 \cdot \mathrm{MED} + 0.2938 \cdot \mathrm{SB} + 0.6277 \cdot \mathrm{BL} + 0.7380 \cdot \mathrm{LANE} + 0.3311 \cdot \mathrm{TREE}$$

where

logit(p) = utility function of the cumulative logit model,
α = intercept parameter of the response level of satisfaction,
WA = type of walking area,
AREA = type of roadside development or landscape,
MOT = motor vehicles per hour in both directions,
SPEED = average motor vehicle speed (km/h),
PED = passed pedestrians per hour on nearest roadside at 5 km/h walking speed,
BIKE = bicycles and mopeds per hour in both directions,
BUF = width of buffer area between walking area and drive lane (m),
PARK = parked motor vehicle on road per 100 m,
MED = median dummy, no median = 0, median = 1,
SB = width of walking area, if this is a sidewalk or bicycle path/track (m),
BL = total width of walking area and nearest drive lane, if walking area is a bicycle lane, paved shoulder or drive lane (m),
LANE = drive lane dummy, four or more drive lanes = 1, one to three lanes = 0,
TREE = tree dummy, one tree or more on road per 50 m = 1, otherwise 0.

Figure 2.6 Jensen (2007) pedestrian LOS model. Source: Jensen, S.U. (2007). Pedestrian and bicyclist level of service on roadway segments. ***Transportation Research Record 2031*****. Washington, DC: Transportation Research Board, p. 48.**

Contrary to many LOS methodologies which treat intersections as minor contributors to overall pedestrian LOS, Crider, Burden, and Han (2001) argue that the intersection is the crucial point in a pedestrian's trip. Indeed, the authors posit that crossing intersections, signalized or unsignalized, often present the greatest barriers to walking (p. 4). Likewise, intersections present similar barriers to bicyclists, and bus stops are the critical component when it comes to evaluating transit LOS. Crider et al. (2001) call these types of analyses "point" level of service, as opposed to "route" or "segment" LOS analyses (p. 4). The authors emphasize the importance of this concept, stating "The importance of this point level assessment lies in its impact on the entire trip for the pedestrian, bicyclist, or transit user. It is literally a 'critical point'" (p. 4). Thus intersections can often be the most dangerous and intimidating aspect of a pedestrian or bicycle trip, making them prime candidates for special attention in LOS analyses.

Recognizing the need for a more thorough investigation of the impact of intersections on the pedestrian experience, Petritsch, Landis, McLeod, Huang, and Challa (2004) developed a separate pedestrian LOS model for signalized intersections. This study used similar participant response and statistical calibration methodology to that used by Landis et al. (2001). The intent of this research was to represent pedestrians' perception of comfort when crossing a signalized intersection. A combination of "Walk for Science" participant observation, video simulation observation, and intersection geometry and performance data were collected to develop the model (p. 1). The researchers used multiple regression and Pearson correlation analyses to determine which roadway and traffic characteristics most affected pedestrians' comfort at intersections, thus developing a pedestrian intersection LOS model.

The factors that affect pedestrian LOS at signalized intersections fall into the categories of perceived conflicts, perceived exposure, and delay (Petritsch et al. 2004, p. 8). The factors found to be most influential in pedestrian intersection LOS and included in the final model are (1) Right- and left-turning vehicle conflicts; (2) Product of traffic volume and traffic speed; (3) Number of lanes to be crossed by the pedestrian; (4) Pedestrian delay; and (5) Presence of right turn channelization islands[1] (pp. 9-10). The Petritsch et al. (2004) pedestrian intersection LOS model equation and factor descriptions are shown in Figure 2.7.

[1] A right turn channelization island is a piece of raised pavement installed between the exclusive right-turn lane and all other directional traffic lanes.

Pedestrian LOS for Signalized Intersections = a_1(RTOR+PermLefts) + a_2(PerpTrafVol*PerpTrafSpeed) + a_3(LanesCrossed$^{0.514}$) + $a_4$ln(PedDelay) + C (1)

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

C = constant

Change in Level of Service Score = - RTCI(0.0027PerpTrafVol – 0.1946)

where

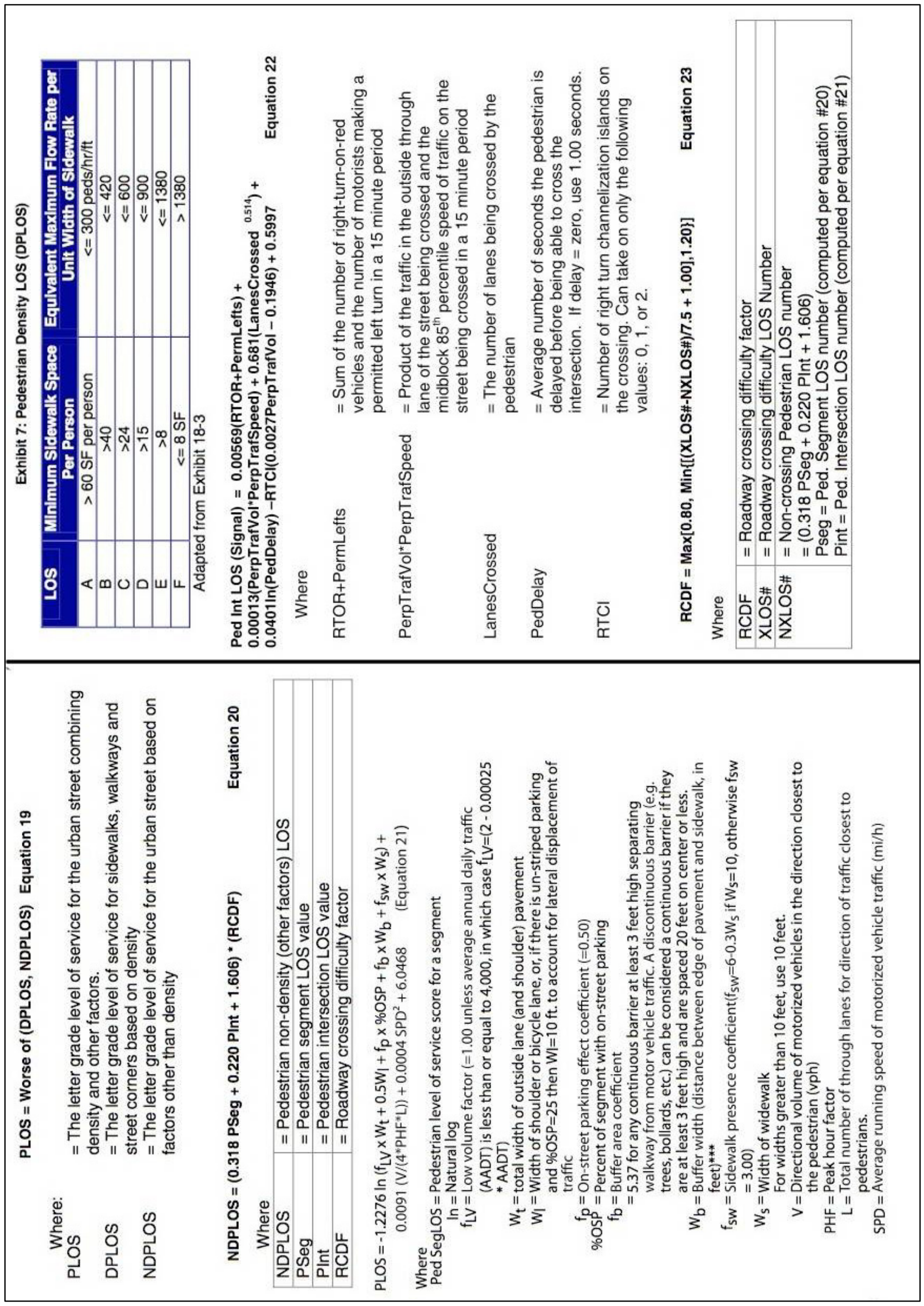
RTCI = number of right turn channelization islands on crossing

Figure 2.7 Petritsch et al. (2004) pedestrian intersection LOS model. Source: Petritsch, T.A., Landis, B.W., McLeod, P.S., Huang, H.F., & Challa, S. (2004). Level of service model for signalized intersections for pedestrians. Sprinkle Consulting, Inc., pp. 9-10.

In a more recent multimodal LOS methodology development, *NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets* (2008) established a series of pedestrian LOS models (as well as bicycle, transit, and motor vehicle LOS methodologies) applicable at the segment, intersection, and facility (entire roadway) level. The NCHRP methodology draws on many of the aforementioned studies, but research was also carried out through a video simulation response method in four different urban locations across the U.S. (p. 1). It is important to note that NCHRP Report 616 is intended for multimodal analysis on urban arterial streets, and thus the methodologies are crafted in order to enable a somewhat equal evaluation of LOS for the four modes of travel on each roadway of interest (p. 1). The methodologies developed in this report (and further elaborated in the *NCHRP Report 616 Users Guide*) will likely be included in the 2010 version of the *Highway Capacity Manual*, due for release in March 2011 (Transportation Research Board 2011).

Like most other mathematical models already mentioned, the *NCHRP Report 616* (2008) methodology used linear regression models and Pearson correlation analyses in order to statistically calibrate participant responses to roadway geometry and traffic conditions (p. 86). Harkening back to the *Highway Capacity Manual* (2000) approach, this report also evaluates pedestrian LOS on the basis of density. The overall pedestrian LOS model in this report is calculated as the worse of Pedestrian Density LOS and Pedestrian Other LOS (which includes segments, intersections, and midblock crossings) (2008, p. 87). The pedestrian segment LOS portion of the model is calculated according to a widely used equation originating from the Florida Department of Transportation *2002 Quality/Level of Service*

Handbook. This model and the relevant factors are very similar to those introduced by Landis, et al. (2001) (2008, p. 88). The pedestrian intersection LOS is computed for signalized intersections using the Petritsch et al. (2004) equation. The final component of the overall pedestrian LOS model is something called a Roadway Crossing Difficulty Factor, which uses the time that pedestrians must wait to cross at unsignalized intersections to represent the difficulty of midblock crossings and its effect on overall pedestrian experience (pp. 88-89). The *NCHRP Report 616 Users Guide* provides a methodology for combining the various separate LOS equations in order to evaluate an entire facility (2009, p. 22). The collection of pedestrian LOS equations and factor explanations provided in the *Users Guide* (2009) are shown in Figure 2.8.



PLOS = Worse of (DPLOS, NDPLOS) Equation 19

Where:

PLOS = The letter grade level of service for the urban street combining density and other factors.

DPLOS = The letter grade level of service for sidewalks, walkways and street corners based on density

NDPLOS = The letter grade level of service for the urban street based on factors other than density

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

Where

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

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

Where

Ped SegLOS = Pedestrian level of service score for a segment

ln = Natural log

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

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

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

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

%OSP = Percent of segment with on-street parking

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

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

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

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

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

PHF = Peak hour factor

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

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

Exhibit 7: Pedestrian Density LOS (DPLOS)

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

Adapted from Exhibit 18-3

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

Where

RTOR+PermLefts = Sum of the number of right-turn-on-red vehicles and the number of motorists making a permitted left turn in a 15 minute period

PerpTrafVol*PerpTrafSpeed = Product of the traffic in the outside through lane of the street being crossed and the midblock 85th percentile speed of traffic on the street being crossed in a 15 minute period

LanesCrossed = The number of lanes being crossed by the pedestrian

PedDelay = Average number of seconds the pedestrian is delayed before being able to cross the intersection. If delay = zero, use 1.00 seconds.

RTCI = Number of right turn channelization islands on the crossing. Can take on only the following values: 0, 1, or 2.

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

Where

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

Figure 2.8 NCHRP (2008) pedestrian LOS models. Source: NCHRP Web-Only Document 128: Multimodal level of service analysis for urban streets: Users guide (2009). National Cooperative Highway Research Program. Washington, DC: Transportation Research Board.

2.4 Bicycle Level of Service

Bicycle LOS measurements and methodologies, similar to pedestrian LOS, can be generally conceptualized as attempts to qualify and quantify the conditions that contribute to a person's feelings of safety, comfort, and convenience when bicycling. Again, some LOS literature addresses the experiences of bicyclists on off-road paths such as multi-use trails, but this paper addresses only bicycle LOS for bicycle experiences on the road. In this context, bicycle LOS is evaluated for roadways with or without marked bike lanes, shoulders, or sharrows.[2] This distinction is extremely important to the definition of bicycle LOS since the bicyclists in these cases are heavily influenced by road and traffic conditions because they are riding with motor vehicles. Similar to pedestrian LOS methodologies, while there have been several attempts to define and measure bicycle LOS, most of the methodologies follow a general three-step process: (1) Determine the factors of the road environment which affect bicyclists; (2) Determine the relative importance of each of these factors; and (3) Assign numerical values to each factor that will sum to a total LOS score. The majority of bicycle LOS methodologies found in the literature are what was defined earlier as "mathematical models," or LOS calculations that consist of statistically-calibrated equations. Thus this section will not be divided into qualitative and mathematical models, but will address all of them together.

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[2] A sharrow is a shared-lane marking painted on the roadway that indicates where bicyclists should ride. These marking are intended to guide bicyclists' location on roads without shoulders, as well as to alert motorists to the presence of cyclists.

As mentioned previously, Dixon (1996) developed a bicycle LOS methodology along with her pedestrian LOS methodology created for Gainesville, Florida's Congestion Management System (p. 1). Dixon's method for developing the bicycle LOS model is the same as that for the pedestrian model, and it also results in an index with a series of factors, each possessing a maximum point value. This bicycle index is also intended to evaluate both road segments and signalized intersections and can be applied at the facility level (p. 1). The bicycle LOS factors identified by Dixon include: (1) Presence and width of a bicycle facility (width of outside traffic lane); (2) Number of driveways and side streets; (3) Barriers to bicycle through movement; (4) Presence of on-street parking; (5) Presence of medians; (6) Sight distances; (7) Bicycle intersection accommodations; (8) Vehicle speed; (9) Motor vehicle LOS; (10) Roadway maintenance issues; and (11) Multimodal support, including transit and policy provisions (1996, pp. 2-5). One interesting attribute of Dixon's bicycle methodology is that the vehicle speed factor is actually calculated as a "speed differential" based on the difference between bicyclists' average speed and motorists' average speed (1996, p. 4). This suggests that bicyclists' comfort may be more affected by relative motor vehicle speed than absolute speed. Dixon's (1996) bicycle LOS index and point values are shown in Figure 2.9.

BICYCLE		
CATEGORY	CRITERION	POINTS
BICYCLE FACILITY PROVIDED (Max Value = 10)	Outside Lane 3.66m (12')	0
	Outside Lane >3.66m-4.27m (>12'-14')	5
	Outside Lane >4.27m (>14')	6
	Off-Street / Parallel Alternative Facility	4
CONFLICTS (Max Value = 4)	Driveways & Sidestreets	1
	Barrier Free	0.5
	No On-Street Parking	1
	Medians Present	0.5
	Unrestricted Sight Distance	0.5
	Intersection Implementation	0.5
SPEED DIFFERENTIAL (Max Value = 2)	>48 KPH (>30 MPH)	0
	40-48 KPH (25-30 MPH)	1
	24-32 KPH (15-20 MPH)	2
MOTOR VEHICLE LOS (Max Value = 2)	LOS = E, F, OR 6 or More Travel Lanes	0
	LOS = D and < 6 Travel Lanes	1
	LOS = A, B, C, and < 6 Travel Lanes	2
MAINTENANCE (Max Value = 2)	Major or Frequent Problems	-1
	Minor or Infrequent Problems	0
	No Problems	2
TDM / MULTI-MODAL (Max Value = 1)	No Support	0
	Support Exists	1
CALCULATIONS	Segment Score [1]	21
	Segment Weight [2]	1
	Adjusted Segment Score [3]	21
	Corridor Score [4]	21 = LOS A

[1] Segment Score = sum of points in the six categories
[2] Segment Weight = segment length / corridor length
[3] Adjusted Segment Score = Segment Score x Segment Weight
[4] Corridor Score = sum of the Adjusted Segment Scores in the corridor

Figure 2.9 Dixon (1996) bicycle LOS index. Source: Dixon, L.B. (1996). Bicycle and pedestrian level-of-service performance measures and standards for congestion management systems. *Transportation Research Record 1538*, Washington, DC: Transportation Research Board, p. 2.

A bicycle segment LOS model based on real-time perceptions has been developed by Landis, Vattikuti, and Brannick (1997). This study uses a methodology very similar to the pedestrian segment LOS also developed by Landis et al. (2001). One-hundred and fifty volunteer cyclists participated in a “Ride for Science” event in which the riders provided their own ratings for each segment of the urban course (1997, p. 120-121). Using Pearson correlation and linear regression analyses, the researchers formulated a model to predict users’ perceptions of roadway and traffic conditions (p. 122). The relevant factors identified by the Landis et al. model include: (1) Directional traffic volume; (2) Total number of through lanes; (3) Posted speed limit; (4) Percentage of heavy vehicles; (5) Trip generation intensity of adjoining land use; (6) Frequency of non-controlled vehicular access (driveways and on-street parking); (7) Pavement condition; and (8) Effective width of outside through lane, including the width of striped bike lane or shoulder (1997, p. 123). The authors of this study particularly note that bicycle lane striping and pavement condition are important factors affecting bicyclists’ level of comfort, even though these aspects are often left out of bicycle LOS studies (pp. 124-125). The Landis et al. (1997) bicycle segment LOS model and factor descriptions are shown in Figure 2.10.

$$BLOS = a_1 \ln(Vol_{15}/L) + a_2 \ln\left[SPD_p(1 + \%HV)\right] + a_3 \ln(COM15 * NCA) + a_4(PC_5)^{-2} + a_5(W_e)^2 + C \qquad (5)$$

where

$BLOS$ = perceived hazard of the shared-roadway environment,
Vol_{15} = volume of directional traffic in 15-min time period,
L = total number of through lanes,
SPD_p = posted speed limit (a surrogate for average running speed),
HV = percentage of heavy vehicles (as defined in the *Highway Capacity Manual*),
$COM15$ = trip generation intensity of the land use adjoining the road segment (stratified to a commercial trip generation of 15, multiplied by the percentage of the segment with adjoining commercial land development),
NCA = effective frequency per mile of noncontrolled vehicular access (e.g., driveways and on-street parking spaces),
PC_5 = FHWA's 5-point pavement surface condition rating, and
W_e = average effective width of outside through lane ($W_e = W_t + W_l - \Sigma W_r$, where W_t = total width of outside lane (and shoulder) pavement, W_l = width of paving between the outside lane stripe and the edge of pavement, and W_r = effective width (reduction) due to encroachments in the outside lane.

Figure 2.10 Landis et al. (1997) bicycle segment LOS model. Source: Landis, B.W., Vattikuti, V.R., & Brannick, M.T. (1997). Real-time human perceptions: Toward a bicycle level of service. ***Transportation Research Record 1578*****. Washington, DC: Transportation Research Board, pp. 123-124.**

In concert with this segment bicycle LOS model, Landis, Vattikuti, Ottenberg, and Petritsch (2002) developed a model for bicycle through movement at signalized intersections. This LOS methodology was also developed by collecting the responses of participants in a “Ride for Science” event (2002, p. 4). Much like the pedestrian intersection LOS model, the factors expected to affect bicyclists’ comfort in the intersection environment can be expressed in the three main categories of conflict, exposure, and delay (2002, p. 7). However, statistical correlation testing proved that intersection delay was not a significant factor in bicyclists’ perceptions of the intersection, perhaps because bicyclists expect to experience the same amount of delay as motor vehicles. The resulting list of bicycle intersection LOS factors from Landis et al. (2002) includes: (1) Total width of outside through lane and bike lane; (2) Crossing distance; (3) Volume of directional traffic; and (4) Total number of through lanes on intersection approach (p. 8). The researchers found that the presence of a striped bike lane through the intersection did not have a strong effect on bicycle LOS, yet the presence of a striped bike lane on the intersection *approach* was a significant beneficial factor for intersection LOS (p. 8). The researchers also note that dedicated right turn lanes and vehicle speed were not included as factors in the final model because of their colinearity with the vehicle volume factor (p. 8). This does not necessarily mean that these factors do not affect bicyclists’ perceptions, but rather the colinearity indicates that dedicated right turn lanes and high vehicle speeds are generally present on the same roadways that have high vehicle volumes. The Landis et al. (2002) bicycle intersection LOS model is shown in Figure 2.11.

$$\text{TM IntBLOS} = a_1 W_t + a_2 CD + a_3(Vol_{15}/L) + C$$

where

TM IntBLOS	= perceived hazard of shared-roadway environment through the intersection
W_t	= 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)
Vol_{15}	= volume of directional traffic during a 15-minute time period
L	= total number of through lanes on the approach to the intersection
C	= constant

Figure 2.11 Landis et al. (2002) bicycle intersection LOS model. Source: Landis, B.W., Vattikuti, V.R., Ottenberg, R.M., & Petritsch, T.A. (2002). Intersection level of service: The bicycle through movement. Sprinkle Consulting, Inc., p. 8.

The Bicycle Compatibility Index, which can be translated into LOS scores, was developed by the Federal Highway Administration (FHWA) using a video simulation model (1998). This model is intended for mid-block street segments on urban and suburban roadways and does not address intersections (p. 3). The relevant factors included in the FHWA bicycle model are: (1) Presence and width of bike lane or paved shoulder; (2) Width of curb lane; (3) Vehicle volume in the curb lane; (4) Vehicle volume in other lanes; (5) Vehicle speed (85th percentile of real speed); (6) Presence of parking lane with over thirty percent occupancy; (7) Type of roadside development; and (8) Adjustment factors based on truck volumes, parking turnover, and right-turn volumes (1998, p. 5). This bicycle model generally requires more traffic and roadway data than other comparable LOS models. The FHWA Bicycle Compatibility Index is shown in Figure 2.12.

$$BCI = 3.67 - 0.966\mathbf{BL} - 0.410\mathbf{BLW} - 0.498\mathbf{CLW} + 0.002\mathbf{CLV} + 0.0004\mathbf{OLV} + 0.022\mathbf{SPD} + 0.506\mathbf{PKG} - 0.264\mathbf{AREA} + \mathbf{AF}$$

where:

BL = presence of a bicycle lane or paved shoulder ≥ 0.9 m
no = 0
yes = 1

BLW = bicycle lane (or paved shoulder) width
m (to the nearest tenth)

CLW = curb lane width
m (to the nearest tenth)

CLV = curb lane volume
vph in one direction

OLV = other lane(s) volume - same direction
vph

SPD = 85th percentile speed of traffic
km/h

PKG = presence of a parking lane with more than 30 percent occupancy
no = 0
yes = 1

AREA = type of roadside development
residential = 1
other type = 0

AF = $f_t + f_p + f_{rt}$

where:

f_t = adjustment factor for truck volumes
(see below)

f_p = adjustment factor for parking turnover
(see below)

f_{rt} = adjustment factor for right-turn volumes
(see below)

Adjustment Factors

Hourly Curb Lane Large Truck Volume[1]	f_t	Parking Time Limit (min)	f_p
≥ 120	0.5	≤ 15	0.6
60 - 119	0.4	16 - 30	0.5
30 - 59	0.3	31 - 60	0.4
20 - 29	0.2	61 - 120	0.3
10 - 19	0.1	121 - 240	0.2
< 10	0.0	241 - 480	0.1
		> 480	0.0

Hourly Right-Turn Volume[2]	f_{rt}
≥ 270	0.1
< 270	0.0

Figure 2.12 FHWA (1998) bicycle LOS model. Source: The bicycle compatibility index: A level of service concept, Implementation manual (1998). Federal Highway Administration, U.S. Department of Transportation.

As also mentioned above in the pedestrian LOS section, Jensen (2007) developed a bicycle LOS model based on facilities and participants in Denmark. This bicycle model was developed using participant responses to video simulations on a variety of urban and rural roadways, and the bicycle facilities represented included on- and off-road paths (pp. 43-44). As noted above, the Jensen model includes a factor related to the number of other bicyclists and pedestrians using the facility, which is rarely a consideration in American contexts (p. 48). Jensen's bicycle LOS model includes fourteen factors, and the factors that were found to most strongly correlate with bicyclist satisfaction include the type and width of the bicycle facility (or traffic lane), distance to motor vehicles, and distance to pedestrians (p. 49). Jensen notes specifically that bicyclist dissatisfaction increases with increasing volumes of motor vehicles, pedestrians, parked vehicles, and vehicle speeds (p. 49). The bicycle model equation and factor descriptions developed by Jensen are shown in Figure 2.13.

$$\operatorname{logit}(p)=\alpha\begin{bmatrix}\text{very satisfied}=-1.3652\\ \text{moderately satisfied}=0.3741\\ \text{a little satisfied}=1.5512\\ \text{a little dissatisfied}=2.4805\\ \text{moderately dissatisfied}=3.8449\end{bmatrix}+\text{AREA}\begin{bmatrix}\text{residential}=0.0557\\ \text{shopping}=-0.3400\\ \text{mixed}=-0.0334\\ \text{rural fields}=-0.0196\\ \text{rural forest}=0.3369\end{bmatrix}-0.0005585\bullet\text{MOT}-2.3895\bullet\text{LBUF}+0.0004691$$

$$\bullet\,\text{MOT}\bullet\text{LBUF}-0.0958\bullet\text{SPEED}+0.000421\bullet\text{SPEED}^2-0.000002913\bullet\text{MOT}\bullet\text{SPEED}+0.0402\bullet\text{LBUF}\bullet\text{SPEED}$$

$$+0.000002446\bullet\text{MOT}\bullet\text{LBUF}\bullet\text{SPEED}-0.001623\bullet\text{PED}+0.0000008309\bullet\text{PED}^2-0.09416\bullet\text{PARK}+1.7782\bullet\text{PATH}$$

$$+1.3938\bullet\text{ULAN}+2.5196\bullet\text{RSHO}+0.2413\bullet\text{DBL}-0.2593\bullet\text{RBUF}+1.2694\bullet\text{SW}-0.6988\bullet\text{BUS}+0.6821\bullet\text{LANE}$$

where

logit(p) = utility function of the cumulative logit model,
α = intercept parameter of the response level of satisfaction,
AREA = type of roadside development or landscape,
MOT = motor vehicles per hour in both directions,
LBUF = width of buffer area between bicycle facility and drive lane on the nearest roadside (m),
SPEED = average motor vehicle speed (km/h),
PED = passed pedestrians per hour on nearest roadside at 20 km/h riding speed,
PARK = parked motor vehicle on nearest roadside per 100 m,
PATH = width of bicycle path/track on nearest roadside (m),
ULAN = width of bicycle lane/paved shoulder (at least 0.9 m wide) on nearest roadside in urban areas (m),
RSHO = width of bicycle lane/paved shoulder (at least 0.9 m wide) on nearest roadside in rural areas (m),
DBL = width of nearest drive lane including bicycle lane/paved shoulder of less than 0.9 m width (m),
RBUF = width of buffer area between sidewalk and bicycle facility/drive lane (m),
SW = sidewalk dummy, sidewalk on nearest roadside = 1, no sidewalk = 0,
BUS = bus stop dummy, bus stop on roadway = 1, no bus stop = 0,
LANE = drive lane dummy, four or more drive lanes = 1, one to three lanes = 0.

Figure 2.13 Jensen (2008) bicycle LOS model. Source: Jensen, S.U. (2007). Pedestrian and bicyclist level of service on roadway segments. *Transportation Research Record 2031*. Washington, DC: Transportation Research Board, p. 49.

Petritsch et al. (2007) used much of the research on bicycle LOS conducted by Landis et al. (1997; 2002) to develop a bicycle LOS model applicable to entire arterial highways. The bicycle LOS model for arterials used participant data from a "Ride for Science" event as well as video simulations combined with Pearson correlation analyses, stepwise regression analyses, and PROBIT modeling (p. 34). The researchers tested the ability of the established Landis et al. (1997; 2002) bicycle segment and bicycle intersection LOS models to predict the participant responses on the arterial roadway course (p. 41). After testing several combinations of models and factors, the researchers came to a final arterial model that is a function of the distance-weighted average segment LOS as well as the number of unsignalized intersections per mile along the facility (2007, p. 41). The number of unsignalized intersections along the arterial roadway was found to be an important representation of conflicts experienced by bicyclists and improved the predictive capacity of the model. The Petritsch et al. (2007) bicycle LOS model for arterials is shown in Figure 2.14.

$$\text{bicycle facility LOS} = a_1(\text{avsegLOS}) + a_2(\text{numunsigpm}) + C$$

where

avsegLOS = distance-weighted average segment bicycle LOS along the facility, and

numunsigpm = the number of unsignalized intersections per mile along the facility.

Figure 2.14 Petritsch et al. (2007) bicycle LOS model for arterials. Source: Petritsch, T.A., Landis, B.W., Huang, H.F., McLeod, P.S., Waddah, F., & Guttenplan, M. (2007). Bicycle level of service for arterials. ***Transportation Research Record 2031.*** **Washington, DC: Transportation Research Board, p. 41.**

Another important mathematical bicycle LOS model is provided in the *NCHRP Report 616: Multimodal Level of Service Analysis for Urban Streets* (2008). Like the pedestrian LOS model developed in this same document, the bicycle LOS model is derived from participant responses to video clips representing roadways in four urban areas throughout the U.S. The researchers used linear regression modeling and Pearson correlation analyses to formulate a model that best correlated participant LOS ratings with roadway geometry and traffic characteristics (2008, p. 82). The resulting overall bicycle LOS model is a weighted combination of an intersection LOS score, the scores of segments between signalized intersections, and a score related to the number of unsignalized vehicle conflicts per mile (p. 82). The factors included in the bicycle LOS model are very similar to those used in the Landis et al. (1997) bicycle segment model. Additionally, as with the pedestrian LOS model, the *NCHRP Users Guide* (2009) provides a methodology for combining the segment and intersection LOS results into a total facility score (p. 15). The bicycle LOS models for segment and intersection developed in this report are shown in Figure 2.15.

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

Where:

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

$$Bint = -0.2144Wt + 0.0153\mathit{CD} + 0.0066\,(V/(4*PHF*\mathit{L})) + 4.1324 \quad \textbf{Equation 16}$$

Where:

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

Figure 2.15 NCHRP (2008) bicycle LOS models. Source: ***NCHRP Web-Only Document 128: Multimodal level of service analysis for urban streets: Users guide*** **(2009). National Cooperative Highway Research Program. Washington, DC: Transportation Research Board, pp. 14-15.**

2.5 Motor Vehicle Level of Service

Motor vehicle LOS measurements are extremely common and ingrained in transportation planning and engineering practice. For this reason motor vehicle LOS is not the focus of this paper. However, one recent and divergent motor vehicle LOS methodology is worth mentioning here, especially because it may be included in the next edition of the *Highway Capacity Manual*. *NCHRP Report 616* (2008) developed an alternative automobile LOS methodology based on user ratings from a set of video simulations (p. 62). Unlike the HCM methodology that focuses on speed only, the NCHRP process resulted in a very long list of relevant variables offered by study participants. However, through a thorough process of correlation and regression analyses, the researchers developed a model for automobile LOS based only on the number of stops per mile and the number of exclusive left-turn lanes along a roadway (*Users Guide* 2009, p. 6). This seems to suggest that frequent delays, whether at intersections or not, rather than overall speed, are what may have the greatest effect on driver satisfaction. While not many factors were included in the final automobile LOS model, it is interesting to note that, based on these initial findings of the NCHRP research, automobile drivers are affected by just as many factors as bicyclists and pedestrians.

2.6 Transit Level of Service

Measuring transit LOS is, to make an understatement, very complex. There are numerous factors that influence users' perceptions of how well a transit service or facility serves their needs, and the importance of these factors varies widely depending on the location of interest. For example, a bus that serves a stop every thirty-five minutes in a suburban location may be considered convenient, while the same service level in a central city context might be unacceptable. Additionally, some aspects of transit service, such as geographic coverage within an area or personal safety at a bus stop, are difficult to measure. Two major sources of transit LOS methodology are explored below.

The *Transit Capacity and Quality of Service Manual* (2003) is generally considered the foremost authority on matters regarding transit LOS concepts. The *Transit Capacity and Quality of Service Manual* (TCQSM) provides guidance on both bus transit and rail transit, though this paper focuses only on bus service. Part three of the TCQSM addresses quality of service for transit in general, with a specific chapter about level of service for fixed-route transit systems. This chapter includes a number of quantitative measures that can be used to evaluate transit LOS (2003, p. 3.1). Transit LOS can be measured at four different spatial levels: route segments, corridors, transit stops, and entire transit systems. For each of these levels, there are two main categories of factors that affect transit LOS: availability, and comfort/convenience (p. 3.29). The TCQSM (2003) does not provide an overall model for evaluating transit LOS. Instead, the document gives several separate LOS scoring guidelines for each different factor. For example, in order to evaluate the availability aspect of LOS at the transit stop level, the TCQSM provides a table that assigns LOS grades A through F based on average transit vehicle headway in minutes (2003, p. 3.30). Likewise, to evaluate the comfort and convenience aspect of LOS at transit stops, the TCQSM provides a table that assigns LOS grades A through F based on passenger standing room (space per passenger) on the transit vehicle (p. 3.45). In the end, the TCQSM provides a large number of different and discrete ways to measure transit LOS. A small sample of these methods is represented in Figure 2.16.

Exhibit 3-1
Quality of Service Framework: Fixed-Route

	Service Measures		
	Transit Stop	**Route Segment**	**System**
Availability	Frequency	Hours of Service	Service Coverage
Comfort & Convenience	Passenger Load	Reliability	Transit-Auto Travel Time

Exhibit 3-13
Fixed-Route Hours of Service LOS

LOS	Hours of Service	Comments
A	19-24	Night or "owl" service provided
B	17-18	Late evening service provided
C	14-16	Early evening service provided
D	12-13	Daytime service provided
E	4-11	Peak hour service only or limited midday service
F	0-3	Very limited or no service

Exhibit 3-12
Fixed-Route Service Frequency LOS

LOS	Avg. Headway (min)	veh/h	Comments
A	<10	>6	Passengers do not need schedules
B	10-14	5-6	Frequent service, passengers consult schedules
C	15-20	3-4	Maximum desirable time to wait if bus/train missed
D	21-30	2	Service unattractive to choice riders
E	31-60	1	Service available during the hour
F	>60	<1	Service unattractive to all riders

Figure 2.16 TCQSM (2003) transit LOS concepts. Source: ***Transit capacity and quality of service manual.*** **(2003). Washington, DC: Transportation Research Board, National Research Council.**

A significantly different transit LOS methodology has been developed in the *NCHRP Report 616* (2008). Unlike the TCQSM methods, this report developed a single model for calculating transit LOS. The first step involved collecting transit user responses from a passenger intercept survey given onboard buses in three metropolitan areas in the U.S. (2008, p. 35). There were so many different factors identified by survey participants that the researchers found it was impractical to develop a model by simply correlating transit characteristics to survey responses. Therefore a model based on other mode choice models and elasticity concepts was developed (2008, p. 72). In other words, the resulting transit LOS model is based on the concept of possible changes in ridership (mode choice) as a result of changes in service characteristics. In simple form, the transit LOS model developed in this report is a function of the ease of pedestrian access to the transit facility as well as measures of passenger wait times and perceived travel times (2008, p. 79). The transit LOS equation and explanatory material, as detailed in the *NCHRP Users Guide* (2009), are shown in Figure 2.17.

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

where:

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

TransitWaitRideScore = f_h * f_{ptt} Equation 5

Where:

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

Figure 2.17 NCHRP (2008) transit LOS model. Source: *NCHRP Web-Only Document 128: Multimodal level of service analysis for urban streets: Users guide* **(2009). National Cooperative Highway Research Program. Washington, DC: Transportation Research Board.**

After addressing level of service for each mode separately, it is worth noting that a recent software-based methodology is available for evaluating multimodal LOS. Dowling Associates, Inc. (2010) has developed a software program called “CompleteStreetsLOS: A Multimodal Level of Service Toolkit.” This software uses the LOS methodologies developed in *NCHRP Report 616* (2008) to calculate LOS for all four modes at once along a single roadway. By providing a simple interface for users to enter the necessary data, this software can potentially be used to not only measure current multimodal LOS on a roadway, but also to predict future LOS based on proposed changes in roadway geometry or facilities. This software is relatively new and thus no reviews of its performance are yet available. However, the concept of a user-friendly and unified interface for evaluating multimodal LOS is extremely valuable, and this will be addressed again in Chapter 5.

2.7 Conclusion

Measuring level of service for transportation facilities has been a familiar concept for planners and engineers for many years. Adding non-motorized and transit LOS into this process is a development which has largely taken shape in the past decade. Much of this renaissance in LOS research is attributable to the growing emphasis on multimodal transportation planning that treats all modes equally. For environmental as well as economic and social reasons, planners and policymakers are coming to realize that pedestrians, bicyclists, and transit riders need to be accommodated—perhaps even encouraged—on the majority of roadways. Motor vehicle LOS measures have, in the past, been one of the only metrics used to evaluate the need for road improvements or capacity increases. Without consideration of other modes of travel, this reliance on automobile LOS has contributed to an overabundance of American roadways which accommodate automobiles sufficiently but are dangerous to bicyclists and pedestrians (some of whom may be accessing transit). Evaluating current and future LOS for transportation facilities is one of the first steps in transportation project design and prioritization. Multimodal LOS methodologies are necessary to work towards evaluating all modes on a level playing field and eventually accommodating these modes equally.

Another important consideration for multimodal LOS methodologies, however, includes the availability of required data and the cost of applying the methods to a large number of roads. If departments of transportation and metropolitan planning organizations are expected to evaluate multimodal LOS at the same scale as they have been evaluating automobile LOS, then the multimodal methodologies will have to be feasible, affordable, and applicable to entire state and local transportation systems. While it is not the aim of this paper to analyze the financial costs or validity merits of each individual LOS methodology, these issues are worth mentioning as they have been one of the greatest challenges to developing useful multimodal LOS evaluation strategies.

For example, subjective methodologies such as Gallin's (2001) pedestrian LOS model can become invalid when implemented by different researchers over time. If this model were to be applied to an entire city's sidewalk system, it would be difficult for one person to do all of the data collection, but on the other hand it would introduce inconsistencies in methodology if it was implemented by several people. A more common problem, though, is the availability and cost of required data. Some mathematical models call for intersection turning movements, traffic volume by lane, and average traffic running speed. In many locations, and especially on collector or lower-order roads, these are not readily available and would be expensive to collect on a large scale. Additionally, data regarding the presence, width, and condition of pedestrian and bicycle facilities is rarely available, and some amount of ongoing fieldwork would be required to gather the pertinent information. In order to accommodate this lack of data, many models provide default values to be used when actual data is unavailable. This technique is not ideal for a truly accurate measure of LOS, but transportation planners and officials will have to find some compromise between staff costs and data precision in order to implement full-scale multimodal LOS evaluations.

Chapter 3

METHODOLOGY DEVELOPMENT

3.1 Introduction

The impetus for this particular project—developing a method for measuring multimodal LOS—began with a joint project between the University of Delaware's Institute for Public Administration (IPA) and the Wilmington Area Planning Council (WILMAPCO). WILMAPCO is the federally-designated metropolitan planning organization for New Castle County, Delaware and Cecil County, Maryland. WILMAPCO wanted to explore possibilities for measuring bicycle, pedestrian, and transit level of service for future application in their studies. Staff from WILMAPCO and Research Assistants from IPA comprised the project team and completed the project in the fall of 2009 and spring of 2010. Factors instrumental in driving the project included the desire to find LOS measurements that were: applicable to the WILMAPCO region, transparent and easy for public officials to understand, used available data, and were financially and technically feasible.

Developing an appropriate multimodal LOS measurement tool for WILMAPCO was a four-fold process: First, perform a literature review of available bicycle, pedestrian, and transit LOS research and methodologies. Second, either choose a pre-existing LOS methodology or develop one specifically for WILMAPCO's purpose. Third, present the chosen or developed measurement tool to WILMAPCO staff and committees to gather feedback and refinement ideas. Fourth, perform a pilot test of the resulting methodology by applying it to a sample roadway. While these four steps were the only requirements for WILMAPCO's initial project, the author, working with WILMAPCO, extended the project further to more fully develop the measurement tool. The remaining steps include: Further development of the LOS methodology based on the results of the pilot test; additional feedback from members of the public and transportation officials; and application of the revised methodology to a number of road segments and intersections in another location in the region. A more detailed explanation of each of these steps, for both the WILMAPCO project and the author's project, is provided below. The process of implementing the resulting LOS methodology through data collection, mapping, and analysis is addressed in Chapter 4.

3.2 Literature Review and LOS Methodology Development

The first step in investigating multimodal LOS possibilities was a literature review to understand the state of the practice. The majority of the literature and methodologies uncovered by this process are presented in Chapter 2. LOS methodologies are generally divided into mathematical and non-mathematical models. These overarching categories were identified to more easily evaluate the pros and cons of each methodology as they related to the goals of WILMAPCO's specific project. Overall, the process of performing a literature review helped the project team understand the data requirements for evaluating multimodal LOS.

The second step for WILMAPCO's multimodal LOS project was to choose or develop a multimodal LOS methodology to implement in the Wilmington region. The project team discussed existing LOS methodologies for the bicycle, pedestrian, and transit modes, but none of these methodologies were completely satisfactory. In general, the more qualitative methodologies such as Dixon (1996) and Gallin (2001) presented the problem of being too inaccurate and lacking some factors that the project team believed to be important. The mathematical models such as *NCHRP Report 616* (2008) were often too complex and required data inputs that were unavailable. The project team desired an LOS measurement tool that was fairly exhaustive and quantitative but at the same time only required data that was readily available or easily acquired. Additionally, the team wanted a measurement methodology that was understandable and transparent to people outside of the field of transportation planning and engineering. Because none of the existing LOS methodologies found in the literature review fit these requirements, the team decided to develop a new multimodal LOS measurement tool.

The project team decided an index tool, similar to those developed by Dixon (1996) and Gallin (2001) was the best place to start. In the field of social research methods, an index is defined as "…a type of composite measure that summarizes and rank-orders several specific observations and represents some more general dimension" (Babbie 2007, p. 154). Indexes measure a general dimension (such as LOS) by accumulating the scores of a number of specific observations (or factors such as sidewalk width) that affect that dimension. Any number of relevant factors can be included, and the contribution of each factor to the total LOS dimension is easily represented by the ratio of that factor's value (its score) to the total index value.

An index methodology also allows one to create discrete categories for each factor in the list. These categories can be exclusive (meaning only one category can be true at a time) or additive (meaning several categories can be true simultaneously). Additionally, index scoring schemes can be set on scales that are positive, negative, or both positive and negative, depending on the nature of the contribution of that factor to the overall score. Figure 3.1 represents a factor with exclusive categories on a positive and negative scale. Figure 3.2 represents a factor with additive categories on a positive scale.

Width of Sidewalk	Pts. (Max 1)
< 5 feet	-1
5 feet	0
> 5 feet	1

Figure 3.1 Index factor with exclusive categories and a positive and negative scale (example only)

Pedestrian Crossing Signal	Pts. (Max 5)
Signal Present	+1
Signal Countdown	+1
ADA Accessible Button	+1
ADA Curb Ramp	+1
Truncated Domes	+1

Figure 3.2 Index factor with additive categories and a positive scale (example only)

Since LOS for each separate mode is considered a different dimension, several indexes were developed by the project team: one each for pedestrian segment LOS, pedestrian intersection LOS, bicycle segment LOS, bicycle intersection LOS, and transit segment LOS. Babbie (2007) enumerates four main steps to constructing an index: selecting possible index factors, exploring their empirical relationships, scoring the factors, and finally validating the entire index (p. 156). This four-step process was employed by the project team and heavily influenced by the literature review, local transportation knowledge, data availability, and information from the feedback groups. For the LOS indexes developed in this project, the total score of the index (the sum of all factors) is a number that can be converted into a letter grade.

Each separate index includes a scoring key that translates the number of total points to a letter grade A through F.

The decision to make two indexes (segment and intersection) for bicycle and pedestrian LOS and one index (segment) for transit LOS was based on common practices found in the literature review. For the bicycle and pedestrian modes, user experiences along a roadway and at signalized intersections are different enough to warrant separate measurement tools, as evidenced by the fact that all of the mathematical models reviewed provide different models for intersections and roadway segments. Additionally, the project team posited that the conditions affecting LOS along a road segment do not necessarily affect the conditions at an intersection and vice versa. Thus two separate indexes needed to be developed so that the score of a certain intersection would not affect the score of its neighboring road segment.

For the purposes of this study, intersection LOS for the bicycle and pedestrian modes is calculated only for signalized intersections. Unsignalized intersections were deemed inappropriate for intersection LOS measurement because they usually present lower levels of traffic, are less of a critical point for pedestrians or bicyclists, and fewer data are available for these intersections. As will be shown later, however, the presence and frequency of unsignalized intersections is incorporated into the bicycle and pedestrian segment LOS indexes. Short road segments were defined as the unit of observation for this study based on the literature review as well as the fact that prevailing conditions along a roadway are less likely to change dramatically within a road segment than within the entire length of a roadway. LOS scores for smaller sections of roadway will be more accurate than LOS scores for entire roadways in which, for example, important factors such as sidewalks and shoulders can come and go.

Road segments are defined as the stretch of road between signalized intersections. This definition is more easily applicable than defining road segments as a certain length. If going by length, one would run into the problem of road segments being interrupted by signalized intersections in some cases. By defining road segments as the stretch between two signalized intersections, the length of segments will vary, but these differences can be normalized with a weighting formula in order to gain a total roadway LOS score, as shown in *NCHRP Report 616* (2008). As will be discussed in Chapter 4, road segments in the implementation phase were largely defined by signalized intersections, but there were exceptions to this definition.

For the development of a transit LOS index, the project team decided to define the unit of observation as a road segment. Transit vehicles do not experience any special conditions at intersections other than the delay experienced by all motor vehicles, and thus intersections did not warrant their own evaluation. As enumerated in the *TCQSM*, transit LOS can generally be evaluated at four scales: transit stop, transit route, corridor, or entire transit system (2003, p. 3-29). Considering the low availability of transit service throughout the suburban areas of the WILMAPCO region, evaluations of corridors or entire transit systems were deemed impractical. Bus service in this region is most easily evaluated at transit stops and along certain routes. However, a "segment" approach was chosen so that the transit LOS scores and maps could be directly comparable to the bicycle and pedestrian segment LOS. As will be discussed later, conditions at transit stops are integrated into the transit LOS segment index.

The separate indexes for each mode were developed using Babbie's (2007) four-step process of constructing an index. The fourth step, validating the entire index, consisted of testing the indexes in the field by applying the measurement tools to actual roadways. This step will be discussed in Chapter 4. The first three steps, however, were undertaken through the processes of literature review and feedback groups. The very first drafts of the indexes were developed based on the literature review and discussions among the members of the project team.

The original draft indexes underwent two major revisions. The first occurred after a February 2, 2010 meeting of WILMAPCO's Non-Motorized Transportation Working Group (NMTWG). Much of this group's feedback was incorporated into the first revision of the indexes before the pilot test was performed on Route 2 (Elkton Road). The second major revision came after the Route 2 pilot test and two more meetings—one with WILMAPCO's Technical Advisory Council (TAC) and one with the WILMAPCO Council. The lessons learned from the pilot study as well as comments from transportation professionals were incorporated into the second major revision of the indexes before they were applied, on the author's initiative, to a second field test of six roadways in Elkton, Maryland.

The three major versions of the indexes are included in Appendices A through C. The following sections detail the evolution of each index and index factor individually. The operational definitions and measurement descriptions for each index factor are included in Appendix D.

3.3 Pedestrian LOS Index Development—Segment

The index for pedestrian segment LOS was originally based on the factors, format, and definitions included in Dixon's (1996) pedestrian LOS index. The index was then adjusted to include factors present in quantitative models such as Landis et al. (2001) and *NCHRP Report 616* (2008) as well as input from the project team. For example, Dixon's index does not explicitly include any factors related to the Americans with Disabilities Act (ADA) with regard to curb ramps or the cross slope of driveways intersecting the sidewalk. The Americans with Disabilities Act of 1990 mandated the development of minimum accessibility standards and guidelines for populations with disabilities (*ADA accessibility guidelines* 2002, p. 1). The ADA Accessibility Guidelines have been updated throughout the years and contain minimum requirements for transportation facilities as well as restaurants, medical care facilities, and recreation facilities. Specific standards and guidelines from ADA documents were not consulted during the development of the pedestrian indexes, but the overall concepts of accessibility and equal access were thought to be important, and thus "ADA accessibility" is addressed throughout the pedestrian indexes.

It is important to note here that the pedestrian segment index originally evaluated both sides of the roadway simultaneously rather than looking at each direction separately. This decision was made based on the format of the Dixon (1996) indexes as well as for simplicity. After the pilot test on Route 2, however, the limitations of this methodology became clear, and the final indexes (for all modes) are based on evaluating and scoring each side of the roadway separately. The total LOS score-to-letter grade conversion chart for pedestrian segment is shown in Figure 3.3.

LOS Scoring	Pedestrian Segment
LOS A→	22 to 25
LOS B→	18 to 21
LOS C→	14 to 17
LOS D→	10 to 13
LOS E→	6 to 9
LOS F→	5 or less

Figure 3.3 Letter grade conversion chart for Pedestrian Segment LOS Index

3.3.1 Presence of Sidewalk [Field Data]

The presence of a sidewalk along the road segment commands the most points in the pedestrian segment LOS index. This factor began with a maximum value of six points and the following scoring categories: Sidewalk not continuous or non-existent (zero points); Sidewalk continuous on one side of the roadway (four points); and Sidewalk continuous on both sides of the roadway (six points). The structure and relative point values of this original index factor were based on the facility presence factor in Dixon's (1996) pedestrian index. This factor methodology was used during the Route 2 pilot study, but the implementation proved difficult. Not only did we find that sidewalk continuity is more nuanced than just continuous or non-continuous, but we also felt that giving a single score to a roadway with a perfect sidewalk on one side and no sidewalk on the other was too inaccurate.

After the Route 2 case study, the pedestrian segment index was altered so that most index factors were applied to each side of the roadway separately. The transition to evaluating each side of the roadway separately resulted in a new "presence of sidewalk" index factor, still worth a maximum of six points, with the following scoring categories: Sidewalk non-existent (zero points); Sidewalk continuous greater than 50% of the segment length (three points); and Sidewalk continuous (six points). The researcher intended to apply this factor methodology to the case study of Elkton roadways but decided in the field that another scoring category, "sidewalk continuous less than 50% of the segment length," was warranted.

The final version of the "presence of sidewalk" index factor is shown in Figure 3.4. This more nuanced measurement of sidewalk continuity is intended to account for situations where a road segment contains a continuous sidewalk facility in front of certain properties but not along the entire segment. In many cases these partial sidewalk facilities may be useful for certain pedestrian movements or provide connection between destinations not located on the road segment of interest. The researcher believed that these facilities deserve credit even if they do not extend the entire length of the study segment.

Presence of Sidewalk	6 Points Max
Continuous	6
Continuous > 50% of segment	3
Continuous <50% of segment	1
Non-existent	0

Figure 3.4 "Presence of Sidewalk" final index factor

3.3.2 Width of Sidewalk [Field Data]

The width of the sidewalk facility is the index factor worth the next highest number of points. Also based on the sidewalk width factor in Dixon's (1996) index, the original "width of sidewalk" index factor was worth a maximum of three points and contained the following scoring categories: Less than five feet wide or containing significant barriers (zero points); Five feet wide and barrier-free (two points); and Greater than five feet wide (three points). The inclusion of a barrier variable in these categories is a way of getting at the "effective width" of the sidewalk. In other words, if a sidewalk facility along a road segment was five feet wide but contained significant intrusions into the sidewalk—such as utility poles, fire hydrants, or benches—that narrowed the useable width of the sidewalk to less than five feet, persons in wheelchairs or two people walking together may have difficulty traversing the area comfortably. In cases where such barriers are present, the project team believed that the segment should not earn points for a sidewalk width that is not always useable. The presence of curb ramps at the intersection of the sidewalk facility and side streets is also evaluated as a barrier. If a curb ramp is not present or not in good repair, this could present an almost insurmountable barrier to wheelchair and stroller users, and thus ADA compliant curb ramps are considered as a part of this factor.

When this original index was presented to WILMAPCO's NMTWG, several members suggested that an additional sidewalk width category, four to five feet, should be added to this index factor. The committee pointed out that the standard sidewalk construction width used to be four feet, and thus many older residential and commercial areas would likely have four foot wide sidewalks. These sidewalk facilities deserve to earn points on the index even if the width is not ideal, so another point category was added. Again, these sidewalk width categories apply only to the effective width of the sidewalk when taking into account barriers and intrusions. The final "width of sidewalk" index factor is shown in Figure 3.5.

Width of Sidewalk	3 Points Max
> 5 ft	3
5 ft and barrier free	2
4-5 ft	1
< 4 ft or containing significant barriers	0

Figure 3.5 "Width of Sidewalk" final index factor

3.3.3 Sidewalk Pavement Condition [Field Data]

The sidewalk pavement condition index factor is based on Dixon's (1996) "maintenance" factor and Gallin's (2001) "surface quality" factor. This factor is intended to loosely quantify the quality of the sidewalk facility in terms of the presence of cracks, bumps, and uneven surfaces in the pavement. While sidewalk pavement condition is not included in the pedestrian LOS mathematical models reviewed above, a similar factor is included in the bicycle LOS models from Landis et al. (1997) and *NCHRP Report 616* (2008). The bicycle pavement condition factor in these models is evaluated using the Federal Highway Administration's five point pavement surface condition rating (*User's Guide* 2009, p. 15). Rather than using the FHWA rating system, which does not fit in well with this index format, the following scoring categories were developed: Poor, not ADA compliant (zero points);

Acceptable, no major cracks or uneven surfaces (one point); and Excellent, completely ADA compliant (two points). The term "ADA compliant," as with other index factors using this term, is not used in this factor to refer to specific ADA requirements. Rather, the term is used to signal to the index user that sidewalk facilities should be scored based on whether or not persons with mobility challenges would be able to safely move along that particular facility considering the pavement condition. The final "sidewalk pavement condition" index factor is shown in Figure 3.6.

Sidewalk Pavement Condition	2 Points Max
Excellent; completely ADA compliant	2
Acceptable; no major cracks or uneven surfaces	1
Poor; not ADA compliant	0

Figure 3.6 "Sidewalk Pavement Condition" final index factor

3.3.4 Potential for Vehicle Conflicts [Remote Data]

The potential for vehicle conflicts index factor is also based on similar factors present in Dixon (1996) and Gallin (2001). As these authors point out, driveways (especially commercial) and side streets present possible conflicts between pedestrians, bicyclists, and motorists either entering or exiting the main roadway. Thus roadways with many conflict points pose a greater danger to pedestrians and bicyclists. The first version of this factor was taken directly from Dixon's (1996) pedestrian index and simply measured whether or not the road segment had greater than twenty-two driveways and side streets per mile (each side is counted separately). After some suggestions from the project team and the NMTWG, the final scoring categories were slightly modified. The final "potential for vehicle conflicts" index factor is shown in Figure 3.7.

Potential for Vehicle Conflicts	2 Points Max
< 15 driveways/mile	2
15-30 driveways/mile	1
> 30 driveways/mile	0

Figure 3.7 "Potential for Vehicle Conflicts" final index factor

3.3.5 Traffic Volume (AADT) [Remote Data]

The amount of motor vehicle traffic on a road has a significant impact on pedestrians' feelings of safety and comfort. The pedestrian segment models developed by Landis et al. (2001), Jensen (2007), and *NCHRP Report 616* (2008) all include a measure of traffic volume. For this index factor, the project team decided to use Average Annual Daily Traffic (AADT) because these were the most readily available traffic volume data. In order to develop scoring categories for AADT, the project team discussed what AADT values were typical on certain types of roadways as well as what breaks in category values would be simple and easy to understand. For example, creating a category of "less than 10,000 AADT" would capture most residential and minor collector streets, while a category of "more than 30,000 AADT" would capture major, multi-lane arterial roads. The final "traffic volume" index factor is shown in Figure 3.8.

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Figure 3.8 "Traffic Volume (AADT)" final index factor

3.3.6 Posted Speed Limit (mph) [Remote and Field Data]

Like traffic volume, the speed of motorized traffic on a roadway also affects pedestrian comfort. Landis et al. (2001), Jensen (2007), Dixon (1996) and *NCHRP Report 616* (2008) all include some version of a traffic speed metric in their pedestrian LOS measurements. Since all of these sources measure and score traffic speed differently, the project team decided that the posted speed limit for a roadway was the most consistent and convenient data regarding traffic speed. The scoring categories were developed based on typical speed limit categories in the region. The first version of this index factor included the following categories: Greater than 45 mph (zero points); 35 to 45 mph (0.5 points); and Less than 35 mph (one point). At the suggestion of the NMTWG, another speed category was added and the total possible points for this factor was raised to two. The committee felt that vehicle speed had a very strong impact on pedestrian comfort and safety and thus deserved to have a larger impact on the LOS score. The final "posted speed limit" index factor is shown in Figure 3.9.

Posted Speed Limit (mph)	2 Points Max
25 or less	2
> 25-35	1
> 35-45	0.5
> 45	0

Figure 3.9 "Posted Speed Limit" final index factor

3.3.7 Percentage of Heavy Vehicles [Remote Data]

Though percentage of heavy vehicles was not included as a factor in any of the pedestrian LOS methodologies reviewed, the project team believed that the amount of trucks on a roadway does, indeed, affect pedestrians' feelings of comfort and safety. The project team hypothesized that the increased noise and particulate matter produced by heavy vehicle traffic would have a negative effect on the overall pedestrian experience. Additionally, percentage of heavy vehicles is included as a factor in many of the bicycle LOS methodologies reviewed. The project team developed three scoring categories that represent low, medium, and high levels of heavy vehicle traffic. The final version of the "percentage heavy vehicles" index factor is shown in Figure 3.10.

Percentage Heavy Vehicles	2 Points Max
0-3%	2
> 3-6%	1
> 6%	0

Figure 3.10 "Percentage Heavy Vehicles" final index factor

3.3.8 Mid-Block Medians [Remote Data]

Dixon (1996) includes the presence of mid-block medians in her pedestrian LOS index and explains, "Medians in a midblock location reduce the number of motorist left-turn conflicts for pedestrians" (7). This factor was included in the first version of the pedestrian segment LOS index and remained intact throughout the revision process. Medians must be a consistent and dominant feature throughout the segment to earn points. The final "mid-block medians" index factor is shown in Figure 3.11.

Mid-Block Medians	1 Point Max
Consistent medians	1
No medians	0

Figure 3.11 "Mid-Block Medians" final index factor

3.3.9 Sidewalk Offset/Buffer [Field Data]

As has been documented in the literature review, the lateral separation between pedestrians and motorized traffic is an important factor in pedestrian comfort. This lateral separation is often accomplished by the use of a buffer or sidewalk offset that places grass, shrubbery, trees, or other barrier objects between the pedestrian facility and the roadway. This factor was originally included in the index and labeled as "buffer." The factor had two scoring categories, based on Dixon's index, which included "no buffer" (zero points) and "continuous buffer, greater than 3.3 feet" (one point). The name of this factor eventually changed to "sidewalk offset/buffer" at the request of members of the NMTWG. Additionally, after the pilot implementation on Route 2, the required width of the offset/buffer for gaining points was changed to three feet in order to make measurement easier. The final "sidewalk offset/buffer" index factor is shown in Figure 3.12.

Sidewalk Offset/Buffer	1 Point Max
Continuous, greater than 3 ft	1
No buffer	0

Figure 3.12 "Sidewalk Offset/Buffer" final index factor

3.3.10 Mid-Segment Crossing Opportunities [Field and Remote Data]

This factor was particularly contentious and went through many revisions before its eventual form in the final index. The scoring of mid-segment crossing opportunities was based on Gallin's (2001) index factor titled "crossing opportunities" as well as discussion among the project team about pedestrians' tendency to cross at points along the roadway most convenient for them. An ideal pedestrian-friendly roadway would provide relatively frequent and safe crossing opportunities so that pedestrians can easily access their destinations. Since the pedestrian segment LOS analysis only looks at road segments between signalized intersections, the target of this measure is crossing opportunities located "mid-block" or "mid-segment."

Members of the NMTWG expressed concern that such "mid-segment" crossings could potentially be more unsafe than providing no crossing opportunities at all and some suggested that this measure be removed from the index. The project team discussed this index factor in depth and eventually decided that official mid-segment crossing opportunities are indeed desirable for two reasons. First, pedestrians will tend to cross the roadway at mid-segment locations whether or not opportunities are provided, and official pedestrian crossings are safer than none at all. Second, the presence of marked and/or signalized mid-segment pedestrian crossings serve to alert motorists to the possible presence of pedestrians. Thus, this index factor was left in the final index, but the maximum score was reduced from two points to one. The factor was originally operationalized to include only marked crosswalks in mid-segment locations, but the presence of four-way stops was added as a possible mid-segment crossing opportunity during the index implementation in Elkton. The final "mid-segment crossing opportunities" index factor is shown in Figure 3.13.

Mid-Segment Crossing Opportunities	1 Point Max
Crosswalk spacing < 1,000 ft	1
Crosswalk spacing > 1,000 ft	0

Figure 3.13 "Mid-Segment Crossing Opportunities" final index factor

3.3.11 Street Trees, Benches, and Pedestrian-Scale Lighting [Field Data]

Pedestrian amenities such as trees, benches, and appropriate lighting can make a walking facility feel more safe and comfortable. In line with the pedestrian "amenities" factors included in Dixon's (1998) index, benches and pedestrian-scale lighting are combined into one index factor while street trees (or shade trees) comprise one single factor. These amenities must be a frequent and dominant feature of the segment in order to garner points. Additionally, because these amenities do not contribute significantly to the absolute safety or convenience of a pedestrian facility, the total maximum point values for each factor are relatively low (0.5 points for each). Figure 3.14 shows both of these index factors.

Street Trees	0.5 Points Max
Dominant feature	0.5
Not present or infrequent	0

Benches or Pedestrian-Scale Lighting	0.5 Points Max
Dominant feature	0.5
Not present or infrequent	0

Figure 3.14 "Street Trees" and "Benches or Pedestrian-Scale Lighting" final index factors

3.3.12 Pedestrian Crashes [Remote Data]

Though not found in any of the pedestrian LOS models reviewed earlier, the project team believed that the pedestrian crash rate along a road segment would be a good indicator of pedestrian safety. Assigning point values to these kinds of data, however, proved to be a difficult task. The original version of this index factor was constructed on a positive scale (where fewer crashes earned higher points), but the final version of the index values this factor as a maximum of zero (where crashes earn negative, not positive points). The method of measuring the value of each crash (i.e. what is a "bad" crash rate and what is an "acceptable" crash rate) also varied with each index revision. This factor was originally conceived of as the number of crashes per segment, then changed to the number of crashes per mile as compared to the county average, and then changed back to the number of crashes per segment. All in all, there were very few pedestrian crashes in New Castle County, and thus an absolute number of crashes is a more appropriate measure than a crash rate.

The original crash rate index factor was conceptualized as a small contributor to overall pedestrian LOS. However, the NMTWG felt that pedestrian crash rates were a strong indicator of how suitable a road segment or intersection is for pedestrian use. At the group's request, the maximum point value for this factor was at one time raised to three. This method worked sufficiently for the pilot project on Route 2, but a problem arose for the index implementation in Elkton. While point level pedestrian crash data were available in New Castle County, Delaware, the same data were not available in Cecil County, Maryland. For this reason—and also recognizing that pedestrian crash rates are not a commonly available set of data in many other locations—the pedestrian crash rate index factor was converted to a negative-scale factor, as described above. Using this format means that the factor can remain in the index whether or not the data are available without significantly affecting the overall LOS score. The final "pedestrian crashes" index factor is shown in Figure 3.15.

Pedestrian Crashes	0 Points Max
None	0
1-2	-1
3 or more	-2

Figure 3.15 "Pedestrian Crashes" final index factor

3.3.13 Cross Slope of Driveways [Field Data]

The cross slope of driveways as they intersect sidewalk facilities is mostly an issue for wheelchair and stroller users. If the cross slope is too steep, these populations can face difficulty (see Figure 3.16). The inclusion of this factor in the pedestrian segment LOS index was suggested by members of the NMTWG as a measure of ADA accessibility. While there is an official accepted driveway cross slope provided by ADA requirements (no greater than 1:50), for ease of evaluation, this index factor was measured in the field by visual inspection rather than mathematical measurement of the slope's angle (*ADA accessibility guidelines* 2002, p. 23). The "cross-slope of driveways" index factor is shown in Figure 3.17.

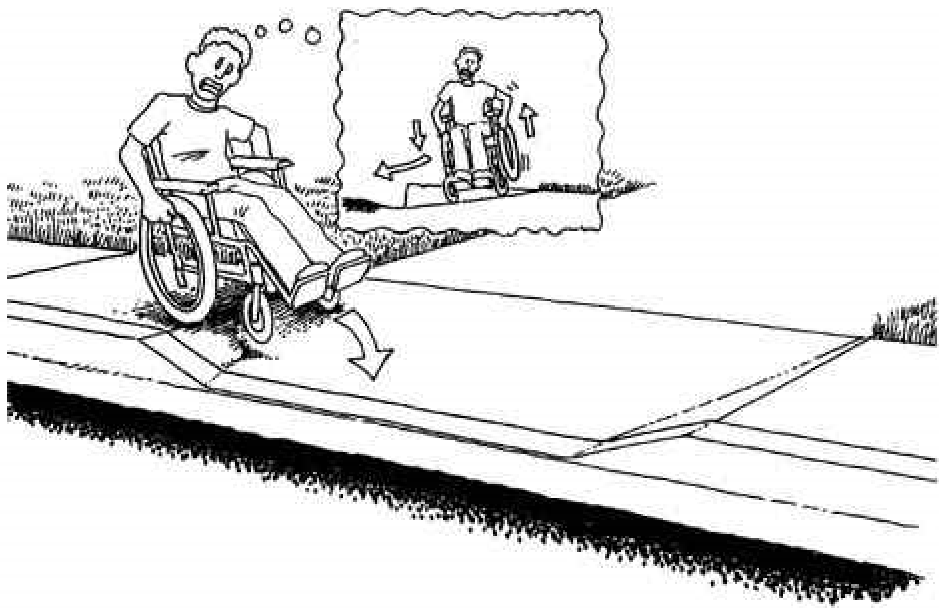

Figure 3.16 Effect of Cross Slope on Wheelchair Users. Source: Federal Highway Administration. "Designing sidewalks and trails for access." Retrieved from http://www.fhwa.dot.gov/environment/sidewalks/chap4a.htm. Section 4.3.2

Cross Slope of Driveways	1 Point Max
Driveways all or mostly at sidewalk grade	1
Driveways not consistent with sidewalk grade	0

Figure 3.17 "Cross Slope of Driveways" final index factor

3.3.14 Walking Appeal [Field Data]

The inclusion of this index factor also came from the NMTWG. Members of this group suggested that the attractiveness and "personal safety" of the area should be incorporated into the evaluation of LOS. In the absence of good examples of objective measures of safety and attractiveness, the project team settled on a "walking appeal" index factor. This is the most subjective measure included in the pedestrian segment LOS index, and it is intended to answer the questions, "Would I feel safe walking here?" and "Would I choose to walk here if I didn't have to?" The "walking appeal" index factor is shown in Figure 3.18.

Walking Appeal	1 Point Max
Pleasant walking environment	1
Unpleasant walking environment	0

Figure 3.18 "Walking Appeal" final index factor

3.4 Pedestrian LOS Index Development—Intersection

The index for pedestrian intersection LOS was also based on the format of Dixon's (1996) index. However, its factors originated mostly from the Petritsch et al. (2004) pedestrian intersection model as well as the model developed in *NCHRP Report 616* (2008). From the start of the index development process, additional factors relating to ADA compliance and accessibility were added. The project team paid particular attention to the conditions of pedestrian crossing signals, crosswalk striping, and curb ramps at signalized intersections. Pedestrian intersection LOS is evaluated for each leg of the intersection separately. For example, a four-way intersection would have four separate LOS scores representing its north, south, east, and west sides. The total LOS score-to-letter grade conversion chart for pedestrian intersection is shown Figure 3.19.

LOS Scoring	Pedestrian Intersection
LOS A→	16 to 18
LOS B→	13 to 15
LOS C→	9 to 12
LOS D→	6 to 8
LOS E→	3 to 5
LOS F→	2 or less

Figure 3.19 Letter grade conversion chart for Pedestrian Intersection LOS Index

3.4.1 Pedestrian Crossing Signal [Field Data]

The presence of pedestrian crossing signals is not found in the pedestrian LOS literature. However, the project team felt that electronic signals at intersections are beneficial to all pedestrians, especially those with mental or physical limitations. This index factor began with only two scoring categories: crossing signal present or crossing signal not present. With input from the NMTWG and members of the project team, more categories were added to this factor to capture the variety of possible crossing signal installations. These added categories include crossing signals with countdowns (which inform pedestrians how much time they have to complete the crossing), and ADA accessible crossing signals (which include a button at a height accessible to wheelchair users, a tactile button for the seeing-impaired, and audible countdown signals for the seeing-impaired). The final version of the "pedestrian crossing signal" index factor is shown in Figure 3.20.

Pedestrian Crossing Signal	3 Points Max
ADA-Accessible signal	3
Signal w/ countdown	2
Crossing signal	1
No crossing signal	0

Figure 3.20 "Pedestrian Crossing Signal" final index factor

3.4.2 Curb at Crossing Point [Field Data]

This index factor is yet another that the project team considered extremely important even though it is not included in other models. The condition of the sidewalk curb at each leg of an intersection is important to the through-movement of pedestrians with physical limitations as well as other pedestrians, such as stroller users. As already addressed in the pedestrian segment section above, the absence of a proper curb cut where the sidewalk meets the road can make these areas difficult for certain users. This index factor evaluates the presence and quality of curb cuts at intersections, including the presence of truncated domes (tactile pavement treatment for the seeing-impaired) as well as curb bulb-outs (or curb extensions) that can make pedestrians more visible to motorized traffic and shorten pedestrian crossing distances (see Figures 3.21 and 3.22). This index factor uses an additive scoring scale, and thus each additional curb treatment (curb cut, truncated domes, and bulb-outs) is awarded one additional point up to a maximum of three. The final “curb at crossing point” index factor is shown in Figure 3.23.

Figure 3.21 Example of truncated domes curb treatment. Source: Safe Routes to School Guide. Retrieved from http://www.saferoutesinfo.org/guide/engineering/sidewalks.cfm

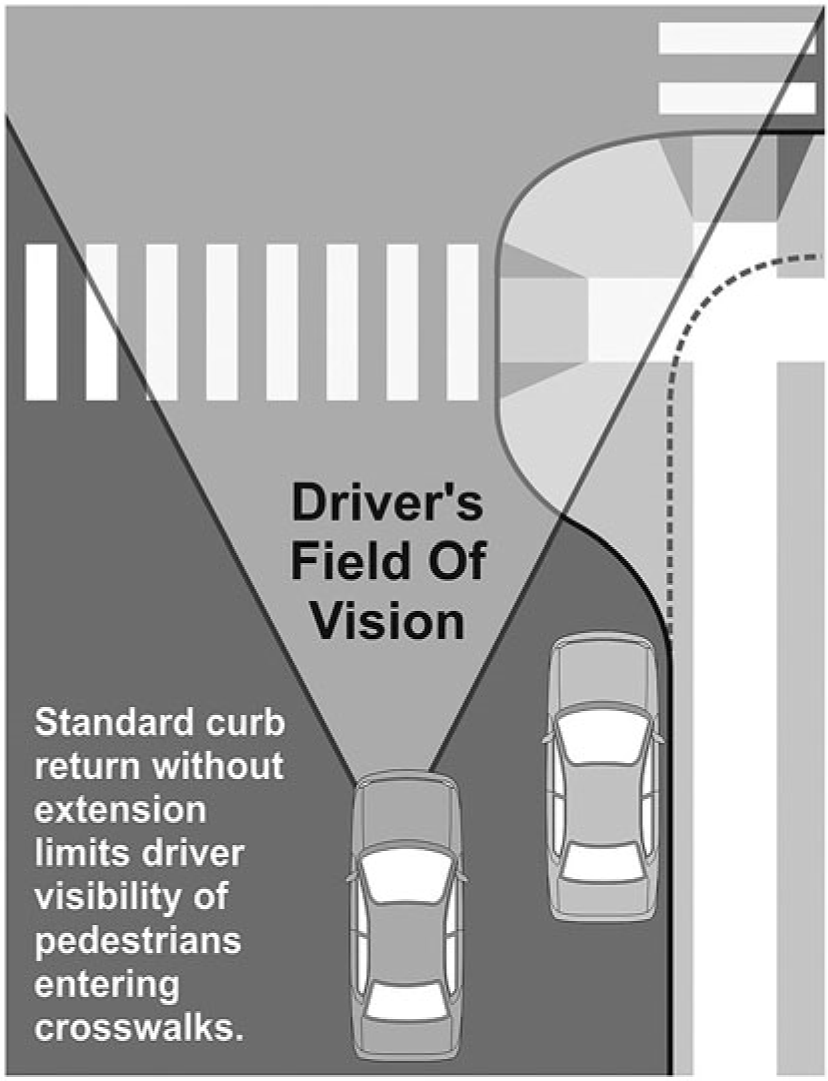

Figure 3.22 Example of bulb-out/curb extension. Source: Institute of Transportation Engineers. Retrieved from http://www.ite.org/css/online/DWUT10.html

Curb at Crossing Point	3 Points Max
ADA curb cut, bulbout, and ADA truncated domes	+1
Curb cut and bulbout	+1
Proper curb cut provided	+1
No curb cut	0

Figure 3.23 "Curb at Crossing Point" final index factor

3.4.3 Crosswalk [Field Data]

Marked crosswalks in the intersection serve two main purposes: to alert motorists to the possible presence of crossing pedestrians and to signal to pedestrians to cross in that location. While the distinction of whether or not a crosswalk is marked was not found in any other models, the project team again thought that this was an important factor affecting pedestrian comfort and safety at signalized intersections. The factor was originally worth a maximum of only one point and included two categories for "marked crosswalk present" or "no marked crosswalk present." However, considering that one function of a crosswalk is to make pedestrian movements more visible to motorists, an additional category of "marked crosswalk with good visibility" was added to the factor. This category is mainly intended to differentiate between hollow or faded crosswalks, which are difficult to see, and striped or color-treated crosswalks that draw increased driver attention (see Figure

3.24). The final version of this index factor is worth a maximum of two points and is shown in Figure 3.25.

Figure 3.24 Differences in Crosswalk Visibility. Hollow crosswalk on left, striped crosswalk on right. Photos from Elkton, MD

Crosswalk	2 Points Max
Marked crosswalk w/ good visibility	2
Marked crosswalk present	1
No crosswalk	0

Figure 3.25 "Crosswalk" final index factor

3.4.4 Crossing Width (lanes) [Remote Data]

The distance that a pedestrian must travel to cross an intersection is represented by the index factor "crossing width." The crossing width affects the duration of "exposure" of a pedestrian in an intersection. This is discussed by Petritsch et al. (2004) and included in their model of pedestrian intersection LOS as the number of lanes being crossed. Dixon (1996) includes crossing width in her index, but the factor is measured in absolute distance (feet) rather than the number of lanes. The project team decided to represent crossing width in number of lanes rather than absolute distance for simplicity of measurement. The scoring categories represent roughly what the project team conceptualized as small, medium, and long crossing widths. This index factor remained the same throughout the revision process and is shown in Figure 3.26.

Crossing Width (lanes)	2 Points Max
2 or less	2
3 to 5	1
6 or more	0

Figure 3.26 "Crossing Width" final index factor

3.4.5 Median/Pedestrian Refuge [Remote Data]

As Dixon (1996) notes, the presence of a median or pedestrian refuge in an intersection shortens the effective crossing width for pedestrians (p. 7). A pedestrian refuge is more important at intersections with long crossing distances, as these may pose difficulties for slower-moving pedestrians or pedestrians that begin crossing late in the signal phase. This index factor, worth a maximum of two points, differentiates between medians that are simply present in the intersection area and medians that actually extend into the crosswalk, indicating their intent as pedestrian refuge areas. Because pedestrian refuges are most appropriate at large intersections with long crossing distances, this index factor is designed to work in concert with the "crossing width" index factor. Therefore even if an intersection scores poorly on the crossing width criteria because the intersection is six lanes wide, the intersection can gain back some points if it provides a pedestrian refuge facility. The final categories and point values of the "median/pedestrian refuge" index factor are shown in figure 3.27.

Median/Pedestrian Refuge	2 Points Max
Median extends into crosswalk	2
Median present	1
No median	0

Figure 3.27 "Median/Pedestrian Refuge" final index factor

3.4.6 Posted Speed Limit (mph) [Remote and Field Data]

This factor is included in the pedestrian intersection LOS index for the same reason that it is present in the segment index. Its scoring categories also underwent the same development process and are shown in Figure 3.9. The posted speed limit value of interest for this factor is the speed limit of the road being crossed by the pedestrian (see explanation in Appendix D).

3.4.7 Traffic Volume (AADT) [Remote Data]

Like the posted speed limit factor, the traffic volume factor is identical to the one present in the segment LOS index, shown in Figure 3.8. The traffic volume is also evaluated for the roadway being crossed by the pedestrian.

3.4.8 Turning Vehicle Conflicts [Field Data]

When pedestrians are crossing an intersection during the correct signal phase ("WALK" pedestrian signal or green traffic signal at locations without pedestrian signals), conflicts between pedestrians and motor vehicles can still arise as a result of motorists turning left on green or turning right on red. This index factor is intended to account for intersections that reduce these possible conflicts, and it is based on Dixon's (1996) "reduced turn-conflict implementations" index factor. The original version included only two categories: right turn on red allowed, and right turn on red not allowed. At the suggestion of the NMTWG, however, the factor was modified to account for left-turning motorist conflicts as well. Figure 3.28 shows how right-turning and left-turning vehicle conflicts can occur.

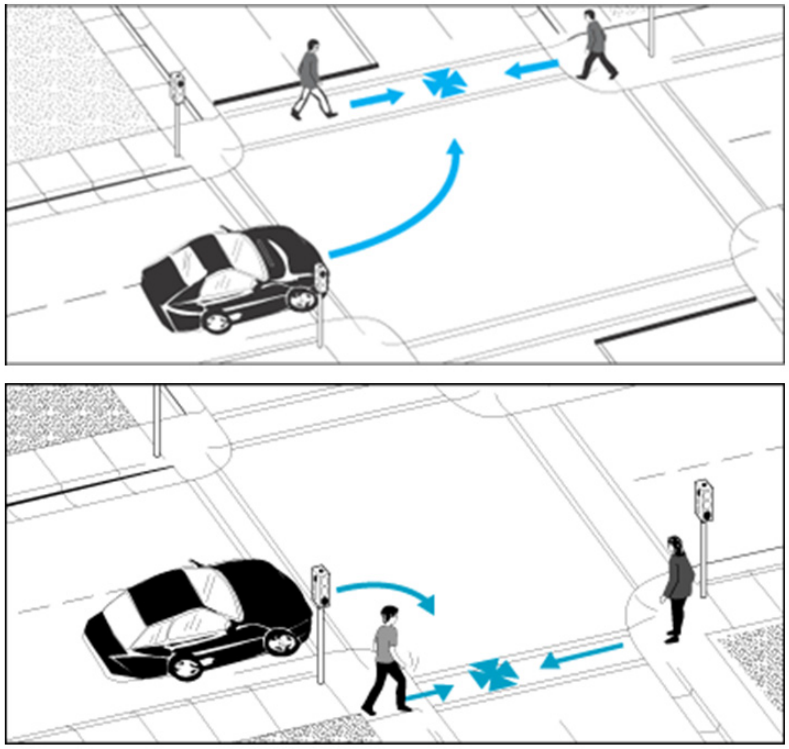

Figure 3.28 Turning Vehicle Conflicts. Source: Pedestrian safety guide and countermeasure selection system. Retrieved from http://www.walkinginfo.org/pedsafe/pedsafe_ca_crashtypes.cfm

The updated "turning vehicle conflicts" index factor included the following categories: Right turn on red *and/or* left turn on pedestrian phase allowed (zero points); and No turning vehicles on pedestrian phase (two points). Unfortunately, the pilot implementation project on Route 2 revealed that evaluating the motorist left-turn permissions at traffic signals was difficult due to traffic sensing and timing technologies. Right-turn permissions are easier to evaluate in the field (or from Google Maps) because they are usually indicated by a permanent sign. The presence of an exclusive pedestrian phase is also relatively easy to evaluate in the field by activating the pedestrian signal and observing the affects. Because of the difficulties encountered in the pilot phase, the scoring categories were modified so that only right-turn permissions and pedestrian signal phases were observed. The final version of this index factor is shown in Figure 3.29.

Turning Vehicle Conflicts	2 Points Max
Exclusive pedestrian phase	2
No RTOR allowed*	1
RTOR allowed*	0

Figure 3.29   "Turning Vehicle Conflicts" final index factor

3.4.9 Pedestrian Crash Rate [Remote Data]

The project team also believed that the number of pedestrian crashes at an intersection is a good indicator of intersection safety for pedestrian movements. This factor is included in the pedestrian intersection LOS index and is identical to the version included in the pedestrian segment LOS index, shown in Figure 3.15.

3.4.10 Right Turn Channelization Islands

This factor was included in the original index but did not end up in the final version. The impetus to include right turn channelization islands in the index originated with the Petritsch et al. (2004) study. These researchers found that the number of right turn channelization islands had an effect on pedestrian perceptions, but this effect was a function of vehicle volumes on the parallel roadway (p. 11). In other words, right turn channelization islands have a detrimental effect on pedestrian comfort at low traffic volumes and a positive effect at high traffic volumes. In addition to the fact that this mathematical relationship was too complex to represent in the index, the NMTWG expressed a similar concern that right turn channelization islands can often be detrimental to the pedestrian experience. Thus this factor was removed from the index before the pilot implementation on Route 2.

3.5 Bicycle LOS Index Development—Segment

Similar to the development of the pedestrian index, the index for bicycle segment LOS was originally based on the factors, format, and definitions included in Dixon's (1996) bicycle LOS index. Once a rough sketch of the index was created, the individual factors went through a series of modifications based on the factors present in the quantitative models, input from the project team, and feedback from WILMAPCO's committees. Many of the members of the NMTWG were bicycle advocates, and their knowledge and experiences provided valuable insight to the index development process. The total LOS score-to-letter grade conversion chart for bicycle segment is shown Figure 3.30.

LOS Scoring	Bicycle Segment
LOS A→	18 to 20
LOS B→	15 to 17
LOS C→	11 to 14
LOS D→	7 to 10
LOS E→	3 to 6
LOS F→	2 or less

Figure 3.30 Letter grade conversion chart for Bicycle Segment LOS Index

3.5.1 Width of Outside Lane [Remote Data]

This index factor is based on the "bicycle facility provided" factor present in Dixon's (1996) bicycle index. As described in Dixon's article, the outside lane width categories are intended to capture not only the lane space available for cyclists, but also the probable existence of a striped shoulder or bike lane (1996, p. 3). Dixon's methodology in essence assumes that an outside lane width greater than fourteen feet indicates the presence of a striped shoulder or bike lane. While this lane width likely does, in fact, mean that a striped shoulder is present, it does not necessarily follow that a marked, official bike lane is provided. The project team felt that marked bicycle lanes deserved points apart from the width of the outside traffic lane. This index factor was originally represented by two different factors: Width of outside lane (worth five points); and Presence of striped/marked bicycle lane (worth two points).

After the original index was presented, members of the NMTWG raised the important point that outside lane widths greater than fourteen feet may not necessarily be good for cyclists because wider lanes tend to allow higher traffic speeds. Thus, the group members believed that a wide lane should not be able to earn five points unless part of that width was a marked bicycle lane. As a result of this discussion, the "width of outside lane" and "presence of striped/marked bicycle lane" factors were combined into one index factor. After the pilot implementation on Route 2 and further discussions with the project team, another scoring category for sharrows (pavement markings that indicate bicycle space within vehicle lanes) was added to the factor. The final version of the "width of outside lane" index factor is shown in Figure 3.31.

Width of Outside Lane (ft)	5 Points Max
Marked bicycle lane	5
Sharrow markings	4
> 14	3
> 12-14	1
12 or less	0

Figure 3.31 "Width of Outside Lane" final index factor

3.5.2 Barriers to Through-Movement [Field Data]

This index factor was originally based on Dixon's (1996) "barriers" index factor and went through several revisions. Barriers to through-movement are conceptualized as anything in the bicycle lane, shoulder, or outside portion of the traffic lane that would force a bicyclist to enter a traffic lane. These barriers can include choke points that cause the bicycle lane or shoulder to disappear (such as narrow bridges); physical intrusions into the shoulder space; drainage grates parallel to the roadway (which can catch bicycle tires); and right-turn slip lanes (that interrupt bicycle through-movement along a road segment). Figure 3.32 shows an example of a right-turn slip lane interrupting the shoulder at the intersection of Elkton Road and Christina Mill Drive in Newark. Drainage grates and right-turn lane interruptions were added to this index factor after the meeting with the NMTWG. The final version of the "barriers to through-movement" index factor is shown in Figure 3.33.

Figure 3.32 Right-turn slip lane bicycle facility interruption. (Note: The white line to the right of the roadway in this photo is a sidewalk and is not analyzed as part of the bicycle LOS index). Image source: Google Earth

Barriers to Thru-Movement	2 Points Max
Free of barriers; drainage grates installed properly; RT lanes do not interrupt shoulder/bike lane	2
Largely free of barriers	1
Significant barriers present	0

Figure 3.33 "Barriers to Thru-Movement" final index factor

3.5.3 Posted Speed Limit [Remote and Field Data]

This index factor was developed in accordance with the pedestrian segment posted speed limit factor. However, the members of the NMTWG felt that vehicle speeds were particularly important to bicycle LOS (more so than pedestrian LOS), so the maximum possible points for this factor were increased from two to three. The final version of "posted speed limit" for the bicycle intersection LOS index is shown in Figure 3.34.

Posted Speed Limit (mph)	3 Points Max
25 or less	3
> 25-35	2
> 35-45	1
> 45	0

Figure 3.34 "Posted Speed Limit" final index factor

3.5.4 Traffic Volume (AADT) [Remote Data]

This index factor is identical to the "traffic volume" factor in the pedestrian segment LOS index, shown in Figure 3.8.

3.5.5 Pavement Condition/Maintenance [Field Data]

The condition of the pavement along a bicycle facility affects both the safety and comfort of cyclists. This index factor is based on the "maintenance" factor included in Dixon's (1996) bicycle index, and it remained relatively constant throughout the index revision process. Potholes, significant pavement cracks, crumbling at the edge of the roadway, and drainage issues affect the scoring of this factor, which is based on a somewhat subjective assessment of field conditions. The "pavement condition/maintenance" index factor is shown in Figure 3.35.

Pavement Condition/Maintenance	2 Points Max
Excellent pavement condition	2
Very few pavement condition issues	1
Major pavement cracks, potholes, standing water	0

Figure 3.35 "Pavement Condition/Maintenance" final index factor

3.5.6 Percentage of Heavy Vehicles [Remote Data]

A factor representing the percentage of the motor vehicle stream comprised of heavy vehicles is included in the models developed in Landis et al. (1997), FHWA's *Bicycle Compatibility Index* (1998), and *NCHRP Report 616* (2008). Members of the NMTWG also confirmed that heavy truck traffic negatively affects the bicyclist experience along a roadway facility. The percent heavy vehicles bicycle segment factor is identical to that of the pedestrian segment LOS index found in Figure 3.10.

3.5.7 Potential for Vehicle Conflicts [Remote Data]

The final version of this factor, as well as the revision process, are identical to the "potential for vehicle conflicts" factor included in the pedestrian segment LOS index and shown in Figure 3.7.

3.5.8 Mid-Block Medians [Remote Data]

The presence of consistent mid-block medians is included in Dixon's (1996) bicycle LOS index as well as her pedestrian LOS index. The effect of medians on bicyclists is essentially the same as their effect on pedestrians, which is to reduce mid-block left-turning vehicle conflicts. The "mid-block medians" factor in the bicycle segment LOS index is the same as the corresponding factor in the pedestrian segment index, shown in Figure 3.11.

3.5.9 Bicycle Crashes [Remote Data]

The development of an index factor representing bicycle crash rates occurred in concert with the development of the pedestrian crash rate factor. The "bicycle crashes" index factor is shown in Figure 3.36.

Bicycle Crashes	0 Points Max
None	0
1-2	-1
3 or more	-2

Figure 3.36 "Bicycle Crashes" final index factor

3.5.10 Bicycling Appeal [Field Data]

As discussed in the pedestrian segment LOS section, the safety and attractiveness of an area was added to the pedestrian index at the request of members of the NMTWG. The bicycle segment index factor similarly asks the questions, "Would I feel safe bicycling here?" and "Would I choose to bicycle here if I didn't have to?" The "bicycling appeal" index factor is shown in Figure 3.37.

Bicycling Appeal	1 Point Max
Pleasant cycling environment	1
Unpleasant cycling environment	0

Figure 3.37 "Bicycling Appeal" final index factor

3.5.11 On-Street Parking

The presence and occupancy rate of on-street parking is identified as an important factor in the following bicycle LOS models: Dixon (1996), FHWA's *Bicycle Compatibility Index* (1998), Jensen (2007), and *NCHRP Report 616* (2008). In all of these cases, on-street parking is considered to have a detrimental effect on bicycle LOS because such facilities expose bicyclists to turning and backing vehicles, car doors, and limited sight distances. However, the detrimental effects of on-street parking proved to be a contentious issue in meetings with the NMTWG. While they agreed that on-street parking does pose some dangers, they also pointed to its traffic-calming effects, which are beneficial to bicyclists. No agreement on the overall effect of on-street parking could be reached, so this factor was removed from consideration.

3.6 Bicycle LOS Index Development—Intersection

Similar to the development of the pedestrian intersection LOS index, the index for bicycle intersection LOS is based on the format of Dixon's (1996) bicycle index, but it also relies heavily on the factors identified in the Landis et al. (2002) bicycle intersection model. Input from the NMTWG was again helpful in this process. Bicycle intersection LOS is evaluated only for the bicycle through-movement on the roadway, and thus it cannot account for bicyclist turning movements. Like the pedestrian intersection LOS methodology, each side of an intersection is evaluated separately on the LOS index. The total LOS score-to-letter grade conversion chart for bicycle intersection is shown Figure 3.38.

LOS Scoring	Bicycle Intersection
LOS A→	11 to 12
LOS B→	9 to 10
LOS C→	6 to 8
LOS D→	4 to 5
LOS E→	2 to 3
LOS F→	1 or less

Figure 3.38 Letter grade conversion chart for Bicycle Intersection LOS Index

3.6.1 Posted Speed Limit and Traffic Volume [Field and Remote Data]

Feedback from the NMTWG suggested that traffic speed and traffic volume through an intersection are two of the most important variables affecting bicyclist comfort and safety. Thus, these two index factors are given relatively high point values—three for speed and two for volume—compared to the total possible twelve points for the bicycle intersection index as a whole. The scoring categories for "posted speed limit" and "traffic volume" are the same as the categories used in the bicycle segment LOS index, shown in figures 3.34 and 3.8.

3.6.2 Width of Outside Through-Lane [Remote Data]

The effective width of the outside through-lane within the intersection is included in the Landis, et al. (2002) bicycle intersection LOS model. This factor in the index is intended to measure the amount of road space available for bicycle movement within the intersection. Adequate space is important considering that bicyclists and motorists often travel through intersections at the same time and therefore must share space. As noted by Landis et al. (2002) in their research findings, the presence of a striped bicycle lane inside the intersection was not found to have a significant effect on bicyclists' perception of LOS (p. 8). Therefore this measure does not differentiate between various bicycle striping possibilities the way its segment LOS counterpart does. Instead, it measures the total width of the outside lane through the intersection. The "width of outside lane" index factor is shown in Figure 3.39.

Width of Outside Thru-Lane (ft)	2 Points Max
> 14	2
> 12-14	1
12 or less	0

Figure 3.39 "Width of Outside Thru-Lane" final index factor

3.6.3 Bike Lane [Remote Data]

While the presence of a bike lane inside the intersection may not greatly affect the bicyclist's experience, the continuation of the bicycle facility at the intersection approach has been found to have a positive effect on bicyclists' LOS ratings (Landis et al. 2002, p. 8). Because of this finding, an index factor was developed that differentiates between bike lanes that are continuous up until the intersection and bike lanes that disappear on the intersection approach (see Figure 3.40). Members of the NMTWG confirmed that this was an important factor. The final version of the "bike lane" intersection index factor is shown in Figure 3.41.

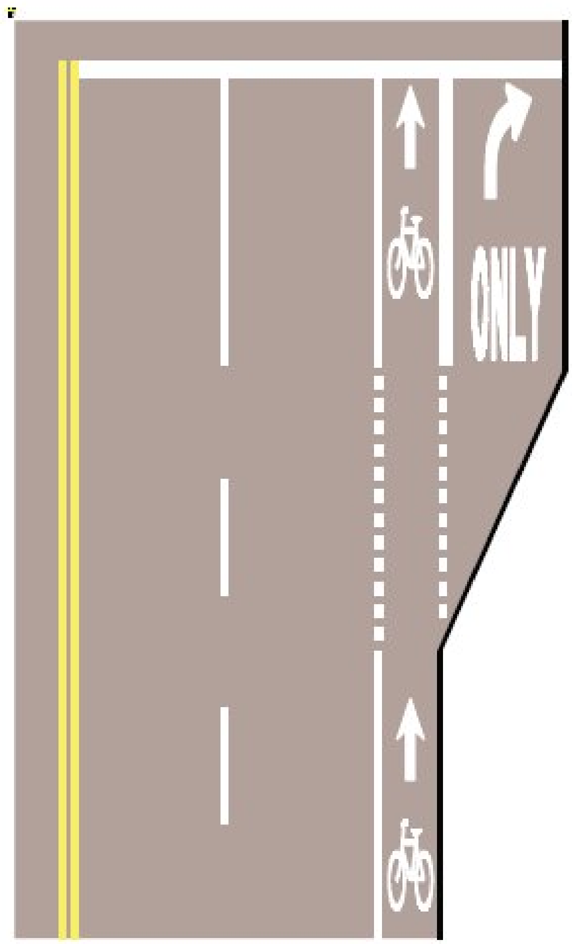

Figure 3.40 Preferred bicycle lane striping at intersection approach. Source: American Association of State Highway and Transportation Officials (1999). Guide for the development of bicycle facilities. Washington, DC: AASHTO, p. 29

Bike Lane	2 Points Max
Continuous through intersection approach	2
Not-continuous	0

Figure 3.41 "Bike Lane" final index factor

3.6.4 Crossing Width (lanes) [Remote Data]

This index factor is identical to the "crossing width" factor in the pedestrian intersection LOS index and shown in Figure 3.26. The justification for this factor is similar to the pedestrian intersection factor as well, representing the fact that additional crossing width (more lanes) exposes bicyclists to more intersection conflicts.

3.6.5 Right Turn on Red Allowed [Field Data]

This index factor is similar to the "turning vehicle conflicts" factor included in the pedestrian intersection LOS index. This factor differs, however, because the project team reasoned that the only vehicle turning movement that would have a significant effect on bicyclist through-movement is vehicles turning right on red. Left-turning vehicles pose less of a threat to bicyclists because cyclists would be riding in the traffic lane along with motor vehicles, whereas pedestrians would be in the crosswalk and perhaps less visible to oncoming left-turning vehicles. Right-turning vehicles, especially in right-turn slip lanes, however, may fail to notice the presence of an oncoming cyclist. While this type of bicycle intersection factor was not found in any of the LOS literature, the NMTWG agreed that it was a valid concern for bicycle intersection safety. The "right turn on red allowed" index factor is shown in Figure 3.42.

RTOR Allowed*	1 Point Max
Not allowed	1
Allowed	0

Figure 3.42 "Right Turn on Red Allowed" final index factor

3.6.6 Bicycle Crashes [Remote Data]

This index factor is identical to the "bicycle crashes" factor in the bicycle segment LOS index, shown in Figure 3.36.

3.6.7 Right Turn Channelization Islands

The presence of right turn channelization islands was originally included in the bicycle intersection LOS index because it was thought to have a similar effect on bicyclists as it does on pedestrians. However, as was described in the pedestrian intersection LOS section above, members of the NMTWG could not come to a consensus on whether right turn channelization islands were a positive or negative attribute of an intersection. Thus, this index factor is not included in the final version of the bicycle intersection LOS index.

3.7 Transit LOS Index Development

The factors included in the transit LOS index are largely based on the LOS measures explored in the *Transit Capacity and Quality of Service Manual* (2003). It is important to note that this index is intended for use in largely suburban locations similar to the WILMAPCO region, which do not usually have extensive transit services available. Therefore the transit LOS index is relatively simple and somewhat more lenient in scoring than the examples provided in the *TCQSM*. Additionally, because buses are the dominant mode of transit in the WILMAPCO region, this transit LOS index is designed to evaluate bus service. The project team agreed that the transit LOS index should focus on the availability aspect of the transit service as well as the conditions of transit stops.

The transit LOS index was never discussed by the NMTWG because so much time was spent discussing the pedestrian and bicycle indexes. Additionally, because the transit LOS index was not applied to the Route 2 pilot study, the other feedback groups did not discuss this index either. Thus, the transit LOS index received much less revision advice from feedback groups than the pedestrian and bicycle indexes received. Transit LOS is evaluated at the segment level rather than system-wide so that it is comparable to the bicycle and pedestrian segment LOS methodologies. Finally, this transit LOS index is only applicable to segments containing a fixed and scheduled transit stop. If a road segment intersects a transit route but there is no scheduled stop, then that segment cannot be evaluated for transit

LOS. The total LOS score-to-letter grade conversion chart for transit segment is shown Figure 3.43.

LOS Scoring	Transit Segment
LOS A→	12 to 13
LOS B→	10 to 11
LOS C→	7 to 9
LOS D→	4 to 6
LOS E→	2 to 3
LOS F→	0 to 1

Figure 3.43 Letter grade conversion chart for Transit Segment LOS Index

3.7.1 Average Headway [Remote Data]

Bus headway represents how often a bus serves a particular stop and can be calculated from published schedules. The frequency of bus service is extremely important to transit users because it determines how long they must wait for the next vehicle. The "average headway" index factor is based on a similar index provided in the *TCQSM*, but the values were modified slightly to better reflect suburban bus scheduling (2003, p. 3-30). The final version of the "average headway" index factor is shown in Figure 3.44.

Avg. Headway (in minutes)	4 Points Max
< 15	4
15-30	3
> 30-45	2
> 45-60	1
> 60	0

Figure 3.44 "Average Headway" final index factor

3.7.2 Hours of Service [Remote Data]

The times of day that transit service is available determines whether the service is convenient only for regular commuters (those who work between the hours of 8 AM and 5 PM) or if it is also convenient for non-work trips or for people who work during non-traditional hours. For example, if a bus line discontinues service after 6 PM, then it would be impossible for anyone to use transit for running evening errands, going to a restaurant, or commuting to a night shift job. The "hours of service" index factor is intended to measure this particular aspect of transit availability. The categories are again loosely based on a similar index found in the *TCQSM* (2003, p. 3-31). Since transit hours of service do not progress in continuous categories like transit headway, this index factor is constructed with a positive, additive scale. The "hours of service" index factor is shown in Figure 3.45.

Hours of Service	4 Points Max
Late evening/night service provided	+1
Early evening service provided	+1
Mid-day service provided	+1
Service at peak hours	+1
Limited or no service	0

Figure 3.45 "Hours of Service" final index factor

3.7.3 Pedestrian LOS

All transit riders are also pedestrians because their access to and from the transit stop is on foot (or wheels). Thus, the pedestrian accessibility to a transit stop is an important factor in transit user satisfaction. The *NCHRP Report 616* (2008) transit LOS model includes a pedestrian accessibility factor represented by the pedestrian LOS of the segment immediately surrounding the transit stop (p. 74). The "pedestrian LOS" factor included in this index follows the same principle and uses the score obtained from the pedestrian segment LOS index to evaluate this index factor. The "pedestrian LOS" index factor is shown in Figure 3.46.

Pedestrian LOS	2 Points Max
A-B	2
C-D	1
E-F	0

Figure 3.46 "Pedestrian LOS" final index factor

3.7.4 Transit Stop Amenities [Field Data]

This index factor is intended to measure the level of comfort provided to transit users at the transit stop location. Benches provide a resting place for waiting passengers while bus shelters offer protection from harsh weather conditions. Bus route and schedule information is also a useful transit stop amenity, especially for first-time riders or visitors. This index factor awards points to the segment if any of these amenities are present at the bus stop. The "transit stop amenities" index factor is shown in Figure 3.47.

Transit Stop Amenities	2 Points Max
Bus shelter	+1
Route/schedule info	+0.5
Bench	+0.5
None	0

Figure 3.47 "Transit Stop Amenities" final index factor

3.7.5 Average Interval Between Stops [Remote Data]

The average interval between transit stops is an indirect way of measuring system-wide availability or coverage. The distance between transit stops is a good indication of how far a transit user might have to travel between their origin/destination and the transit stop. While system availability is a complex measure that would likely require GIS analysis, the interval between transit stops is easily measurable at a segment or roadway level. The "average interval between stops" index factor is shown in Figure 3.48.

Avg. Interval Between Stops	1 Point Max
1/4 to 1/2 mile	1
> 1/2 mile	0

Figure 3.48 "Average Interval Between Stops" final index factor

3.8 Conclusion

The development of these multimodal LOS indexes was largely based on literature research and feedback from citizens and transportation experts. However, the implementation of the indexes on actual roadways played a significant role in refining the index factors and scoring processes. The next chapter describes how data for the LOS indexes were collected on sample roadways in the WILMAPCO region as well as from remote sources. The process of analyzing and mapping the data is also detailed, followed by a discussion of the results of implementing each index on real roadways.

Chapter 4

DATA COLLECTION AND RESULTS

4.1 Introduction

The implementation of the LOS indexes involved remote and field data collection, analysis, and GIS mapping of the results. The data collection and mapping processes for the two phases of the project (Route 2 and Elkton, MD) were similar but not entirely identical due to differences in index format and the GIS software used for each study. For the pilot implementation of the indexes on Route 2, the majority of the remote data collection and GIS mapping occurred at the WILMAPCO office with MapInfo software. For the index implementation in Elkton, most of the remote data collection and mapping took place at IPA's office with ArcGIS software.

Due to time limitations, the transit LOS index was not applied to Route 2 for the pilot study. The transit LOS index was applied to the analysis segments in the Elkton study, but transit service was sparse on the particular segments in the study, and thus the transit LOS index received much less testing overall than the pedestrian and bicycle LOS indexes. The details of data collection, mapping, and results are explained for each project phase separately in the following sections. More emphasis is placed in this chapter on the Elkton, MD study because this study was more extensive and used the finalized versions of the LOS indexes.

4.2 Data Collection, Analysis, and Mapping of LOS on Route 2

The area of interest for the Route 2 pilot study spanned the length of Route 2 from its start at Main Street in Newark to the Delaware/Maryland state line, a distance of about 2.5 miles (see Figure 4.1). This roadway was chosen for the pilot study due to its proximity to WILMAPCO and the University of Delaware, as well as the fact that roadway conditions and surrounding land uses vary drastically along this small stretch of roadway. The beginning of the Route 2 study segment is located very near the University of Delaware campus and is surrounding by medium-high density commercial and residential land uses. This area also sees a fair amount of pedestrian and bicycle activity. To the south of the University, however, Route 2 becomes a high-speed four-lane highway as low-density residential, commercial, and industrial land uses emerge. This drastic change in road character in such a short distance provided a good test case for measuring multimodal LOS. Additionally, soon after the implementation of this pilot study, DelDOT began major multimodal renovations on Route 2, which provides an opportunity for a “before and after” LOS study in the future.

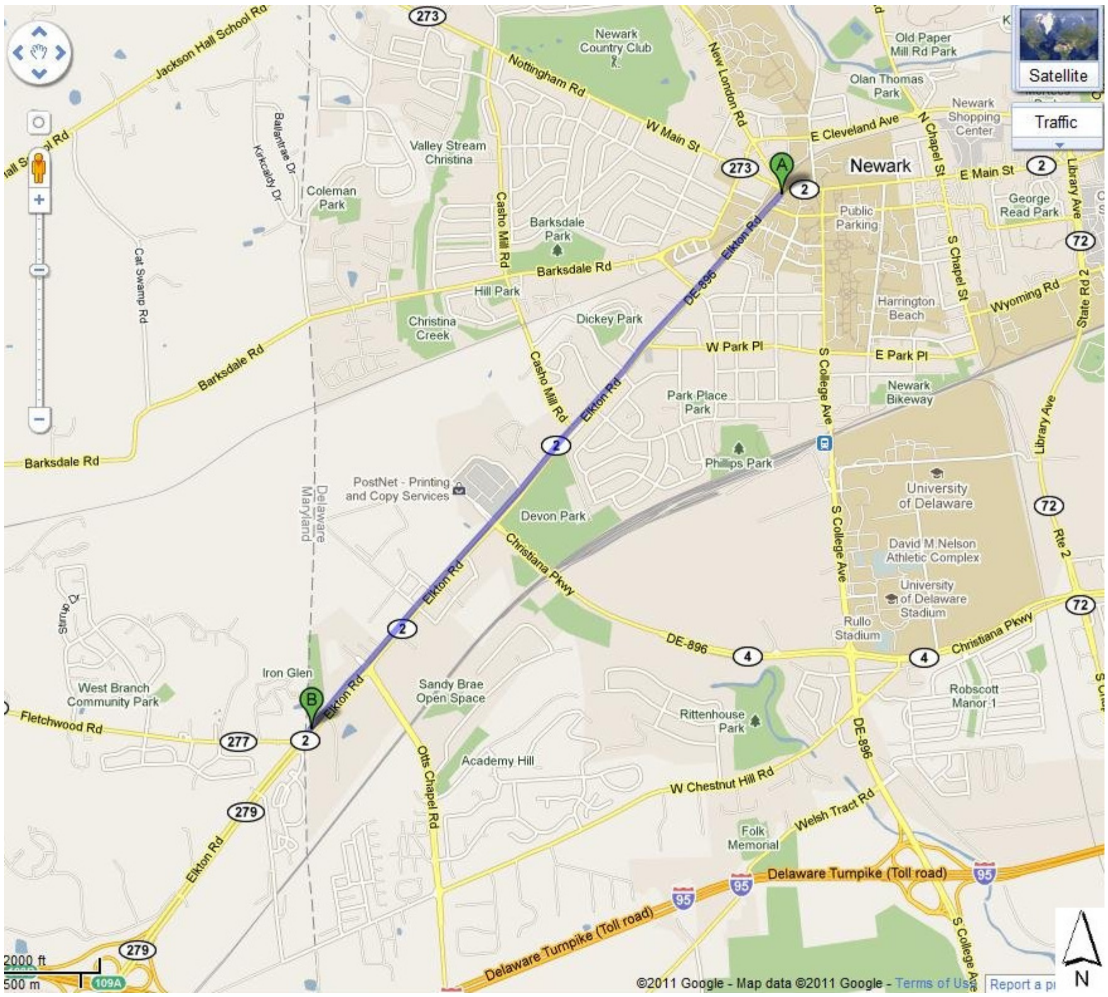

Figure 4.1 Route 2 Pilot Study Segment. Image Source: Google Maps

The pilot study began by defining the segments and signalized intersections of interest along Route 2. A preliminary map of segments and intersections was prepared in MapInfo, and then the researchers (Claire Beck and Kristen Eaton) walked along the study area in order to refine the segment and intersection locations. The resulting defined road segments are largely divided by signalized intersections, but some segments begin and/or end at unsignalized intersections. This segment definition was employed in cases where the distance between signalized intersections was too great for meaningful analysis, or where an unsignalized intersection represented an important breaking point in roadway characteristics. Each segment and signalized intersection leg was assigned an alphabetical letter so that data sheets could be produced (see Figure 4.2). To prepare for data collection in the field, data collection sheets and detailed maps were produced in order to keep track of measurements, scores, and any issues that arose (see Figure 4.3).

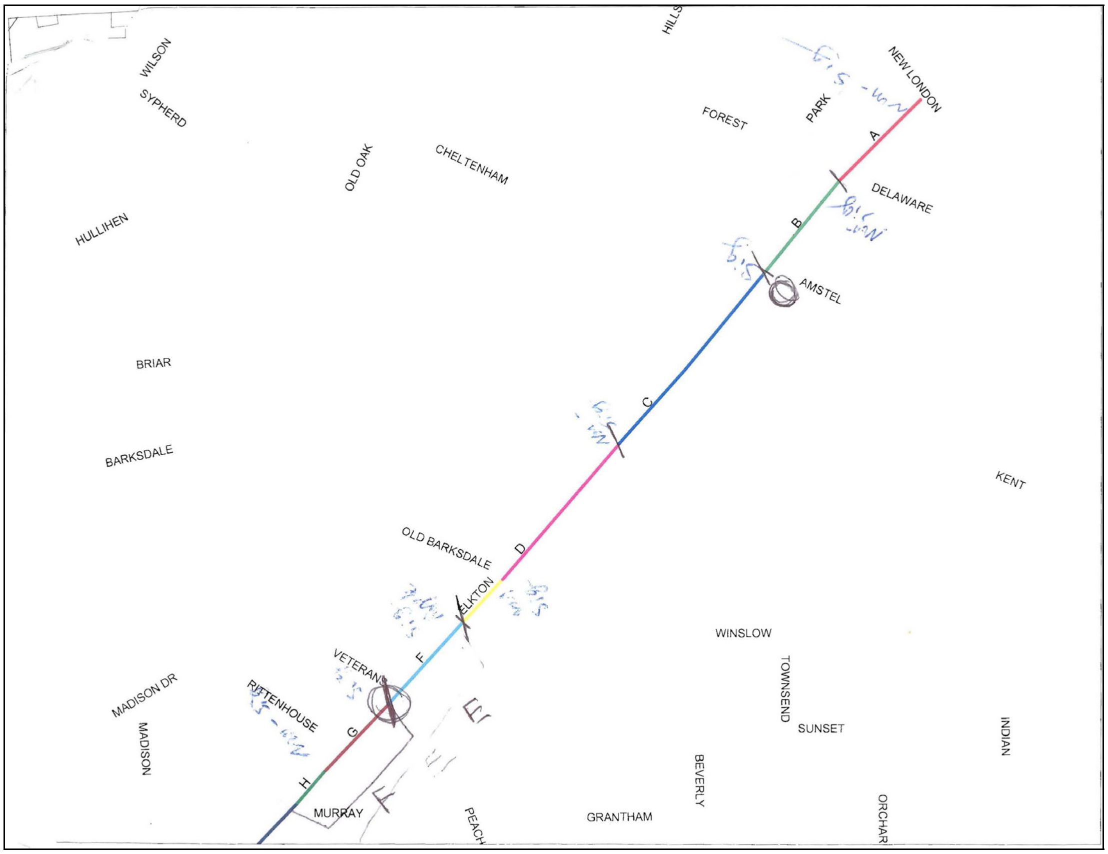

Figure 4.2 Sample segment and intersection definition map on Route 2 (image scan of field sheet with manual segment definition corrections)

Pedestrian Intersection Scoring Chart

Intersection	Pedestrian Crossing Signal	Curb at Crossing Point	Crosswalk Present	Speed Limit	Turning Conflict
Apple West East North South					
Christina West East North South					
Haskell West East North South					
Amstel West East North South					
Veterans West East North South					
Park West East North South					
Thorn West East North South					
Casho Mill West East North South					
McIntyre West East North South					

Figure 4.3 Sample scoring chart for Route 2

The field data collection on Route 2 took place on March 21st, 2010. Claire Beck and Kristen Eaton rode bicycles from the intersection of Main Street and Route 2 to the state line, and then walked the road length back to Main Street to collect data. The researchers brought along maps, data collection sheets, a camera, a notebook, and a tape measure. The researchers walked the length of each individual segment, taking measurements, noting sidewalk or bicycle facility issues, and taking pictures on both sides of the roadway. At the end of each segment, the researchers worked together to score each factor on the pedestrian and bicycle segment LOS indexes based on observations and measurements. A similar process was employed at intersections, whereby the researchers crossed each leg of the intersection, observing the traffic signals, traffic turning movements, and pedestrian signals. Index factors for each leg of the intersection were then scored separately. At intersections where no crosswalks or crossing signals were present, the researchers did not always cross each leg of the intersection for safety reasons. Once the field data was collected, the scores were transferred to an electronic scoring sheet file.

The next step involved creating a GIS file that could be used to represent the data geographically. Using MapInfo, the researchers created a linear layer for Route 2 segments and a point layer for Route 2 intersections. The linear layer is comprised of multiple segments, each with individualized attributes. Likewise, each leg of each intersection is a separate object with its own attribute table. These layers were overlaid onto the DelDOT centerline file so that other surrounding roads could be represented. Each attribute table for segments and intersection legs was constructed to have an ID field (segment or intersection name) along with fields for each index factor, a total index score field, and an LOS letter grade field (see Figure

4.4). After the map and attribute tables were created, the field data were added to the attribute tables.

After field data were collected and documented, the next step was to obtain and record the remote data for the remainder of the index factors. Average Annual Daily Traffic (AADT) and heavy vehicle percentage data were obtained from the DelDOT centerline file. Pedestrian and bicycle crash data were obtained from a DelDOT/WILMAPCO shapefile of pedestrian and bicycle crashes from the years 2006 through 2008. The rest of the data (including "width of outside lane" and "potential vehicle conflicts") were obtained from aerial photos imported into the existing map. Detailed data collection information is provided in Appendix D.

Once all of the required data were entered into each attribute table, a total LOS score and letter grade was calculated for each segment and intersection leg (see Figure 4.4). A color scheme for representing LOS letter grades was devised, and this symbology was applied to the segments and intersections. This process was employed for two different maps, one each for bicycle and pedestrian LOS. The result is two maps representing segment and intersection LOS for the study length of Route 2. The resulting maps are shown in Figures 4.5 and 4.6.

SEG_ID	OF_SIDE	OF_SIDE0	CRASH	CONFLICT	VOLUME	SPEED	VEHICLES	CONDITION	OFFSET	MEDIAN	TREE	BENCHES	SLOPE	APPEAL	OPPORTUNIT	SCORE	LOS
O	0	0	2	0	0.5	0	2	0	0	1	0	0	0	0	0	5.5	E
P	4	2	3	1	0.5	0	2	1	1	1	0	0	0	0	0	15.5	C
M	0	0	3	2	0.5	0	1	0	0	1	0	0	0	0	0	7.5	E
L	0	0	3	2	0.5	0.5	1	0	0	1	0	0	0	0	0	8	E
K	4	1	3	2	0.5	0.5	1	1	1	1	0	0	1	0	0	16	C
J	4	1	3	2	0.5	0.5	1	1	0	1	0	0	1	0	1	16	C
I	4	0	3	2	0.5	0.5	2	0	0	1	0	0	0	0	1	14	D
H	6	1	2	2	0.5	1	2	0	0	1	0	0	0	0	1	16.5	C
G	6	0	3	1	0.5	1	2	0	0	1	0	0	0	0	0	14.5	C
F	6	0	2	1	0.5	1	2	0	0	1	0	0	0	0	0	13.5	D
E	6	0	3	2	0.5	1	2	0	0	1	0	0	0	0	1	16.5	C
D	4	0	2	0	0.5	1	1	0	0	0	0	0	0	0	0	8.5	E
C	6	1	3	0	0.5	1	1	1	0	0	0	0	0	1	0	14.5	C
B	6	1	3	0	0.5	1	1	1	0	0	0	0	0	1	0	14.5	C
A	4	1	3	2	0.5	1	1	0	0	0	0	0	0	0	0	12.5	D
N	4	2	3	2	0.5	0	1	0	1	1	0	0	1	0	0	15.5	C

Figure 4.4 Example Pedestrian Segment GIS Attribute Table

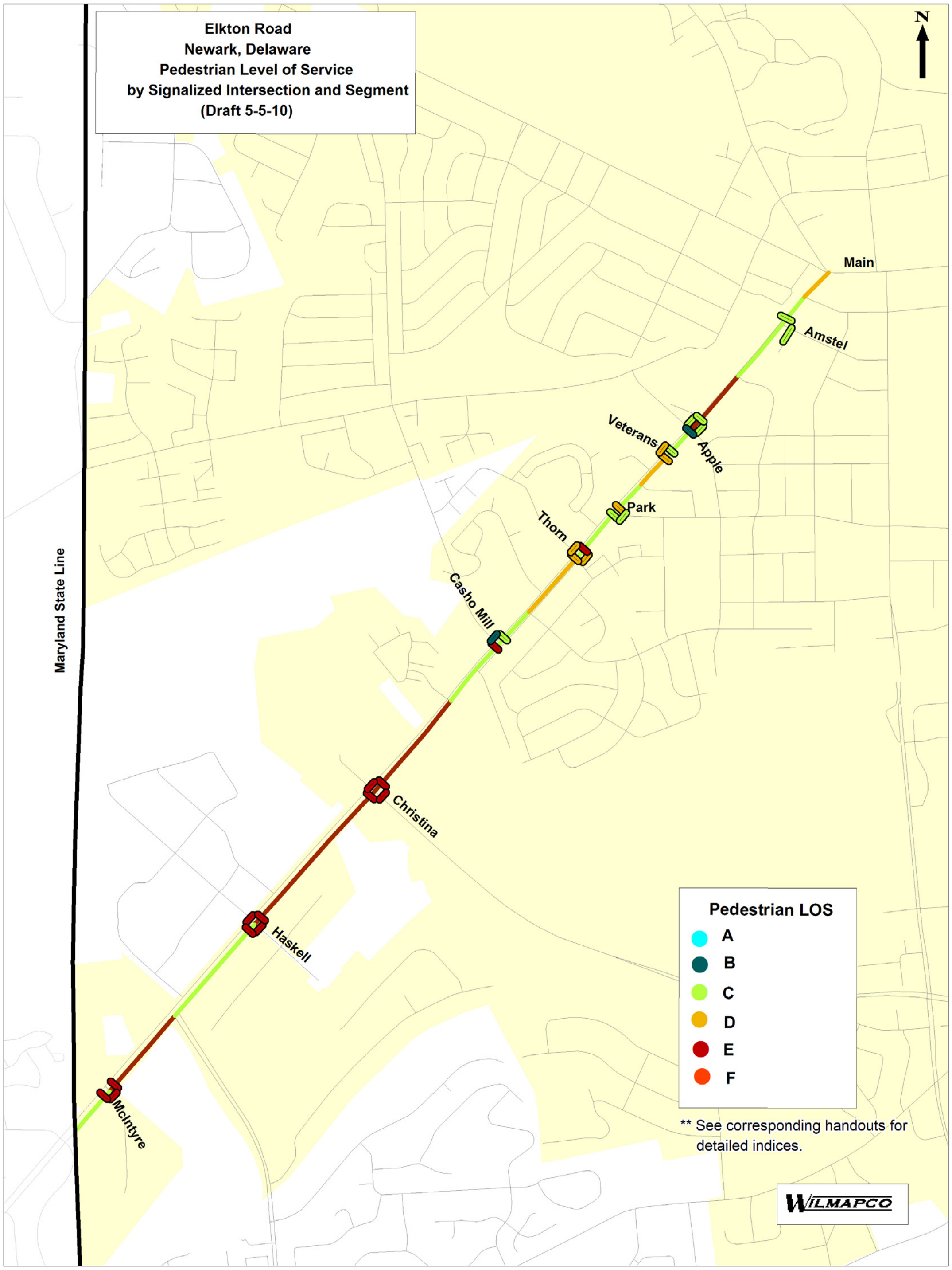

Figure 4.5 Route 2 Pedestrian Segment and Intersection LOS Map (no scale)

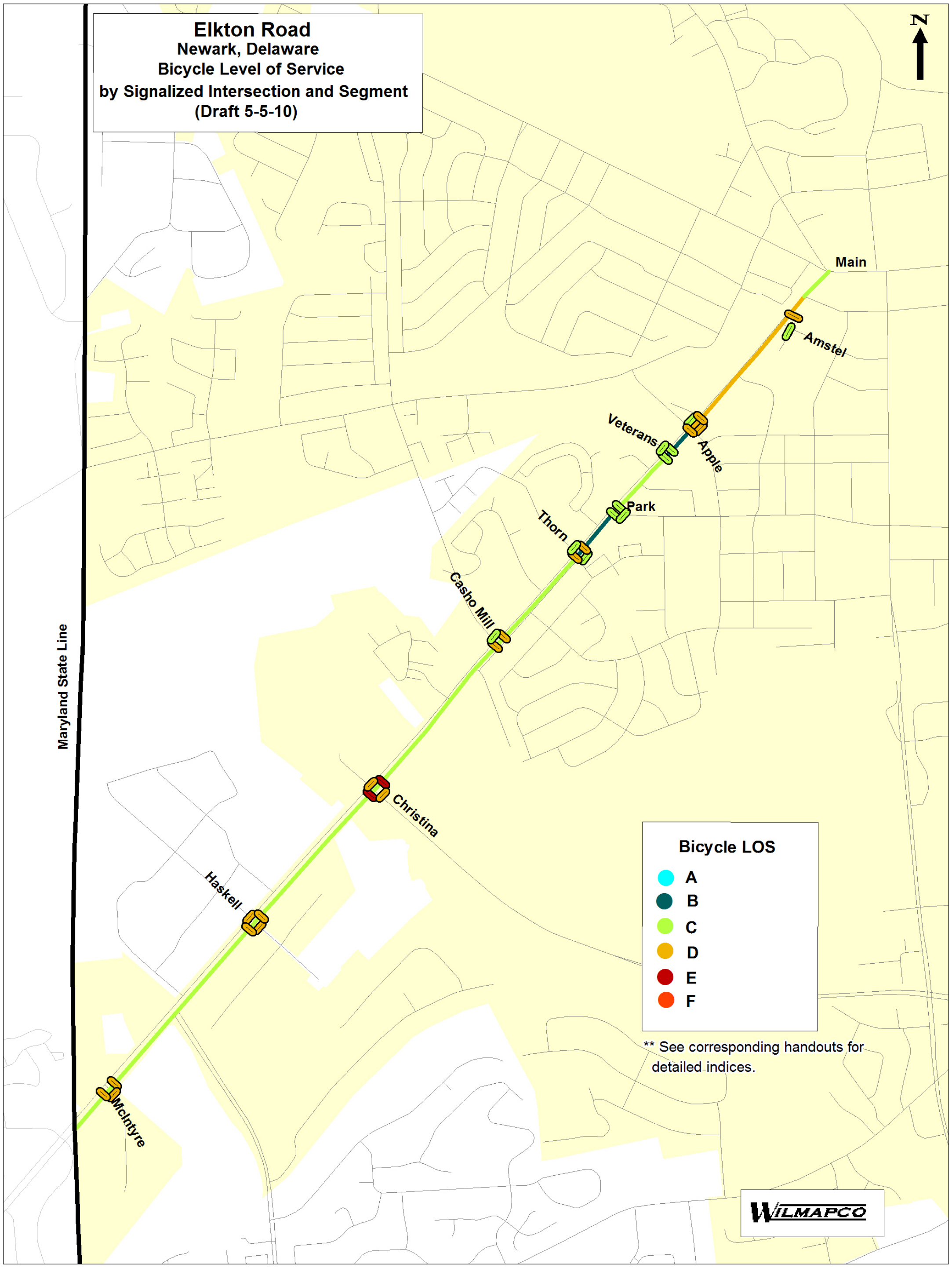

Figure 4.6 Route 2 Bicycle Segment and Intersection LOS Map (no scale)

A few things should be noted about the Route 2 LOS maps. First, Route 2 is referred to as "Elkton Road" on these maps as that is how the road is known locally. Throughout this paper, however, Route 2 is used to avoid confusion with the LOS index implementation in Elkton, Maryland. Additionally, the segment LOS in the Route 2 study was evaluated for both sides of the roadway at once, so each segment is represented by one LOS score instead of two lines representing each direction. The LOS maps for Elkton, MD will represent segment LOS with two lines per roadway, representing each direction of bicycle or pedestrian travel individually.

With regards to the mapping of intersection LOS, the short lines on each side of the intersection represent the direction of travel for either the pedestrian or bicyclist. For example, a line on the east side of an intersection represents a bicyclist traveling north on Route 2 and a pedestrian traveling either north or south as they cross the east side of the intersection. Some intersections are represented by less than four lines due to the fact that not all intersections are "four-way-stop" intersections with four distinct crossing points. For example, at the intersection of Route 2 and Veterans Road, there is no road extending to the east of Route 2, and thus the east side of the intersection is not considered a crossing point (see Figure 4.7). For the Route 2 study, if there was no crossing point on one or more sides of an intersection, that side was not evaluated for bicycle or pedestrian intersection LOS.

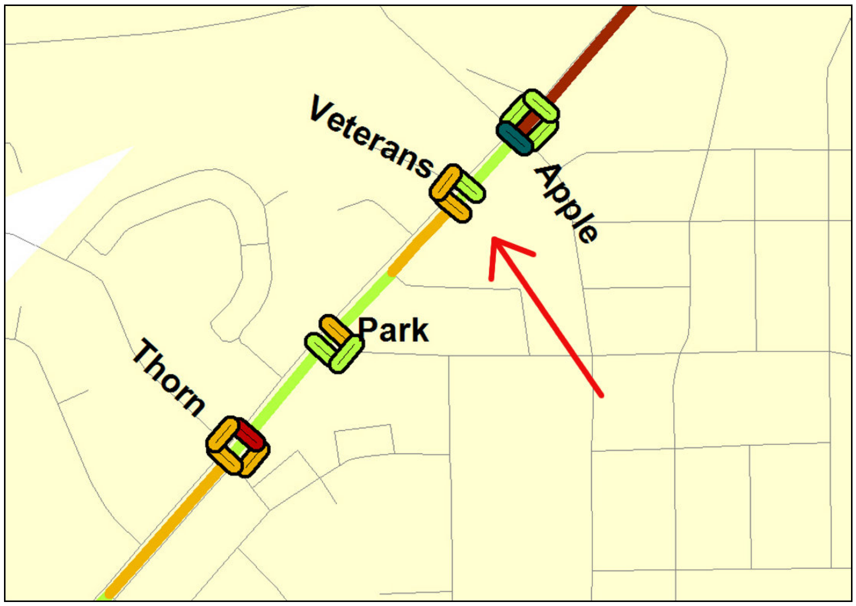

Figure 4.7 Missing Intersection Leg Example (excerpt of Figure 4.5)

The conceptualization of bicycle intersection movements differed during the Elkton, MD study, and this represents a significant difference between the implementation of the indexes between the two studies. In the Elkton, MD study the pedestrian LOS intersection legs of interest were determined in the same way as the Route 2 study, but bicycle LOS intersection legs were evaluated based on whether or not it was possible for a bicycle to be traveling in a certain direction. To use the Route 2 and Veterans Road example again, it would be impossible for a bicyclist to travel from east to west through the intersection because there is no roadway to the east. Thus, there would be no bicycle intersection LOS calculated for that intersection movement, represented in Figure 4.4 by the line on the north side of the intersection. In the Elkton, MD study, there would instead be a line on this map on the east side of the intersection representing the northward movement of bicyclists. Even though the bicyclist would not be "crossing" a cross-street to the east, they would still be exposed to the other elements of the intersection environment, and thus intersection LOS should be evaluated for this movement. Therefore in the Elkton, MD study, the missing legs of intersections on the maps are different for the bicycle and pedestrian modes, whereas the intersections for both modes are represented identically in the Route 2 study.

4.3 Results of LOS Analysis on Route 2

As the above maps show, LOS scores for segments and intersections vary quite a bit along the length of the Route 2 study area. In the GIS attribute tables for each segment and intersection leg, the values for each index factor were recorded as fields in the table. This allows researchers to easily see which index factors contributed most significantly (positively or negatively) to individual LOS scores. For pedestrian LOS most of the differences in scores along Route 2 can be attributed to the presence or absence of sidewalks and crosswalks. For bicycle LOS, the segment scores are relatively stable throughout the study area due to the presence of a constant bicycle lane. The bicycle intersection scores were most heavily influenced by speed limits and crossing widths. In order to demonstrate the effects of roadway and facility conditions on final LOS scores, it is helpful to look closely at a few specific examples of segments and intersections represented on the maps and discuss why they received the LOS scores that they did.

4.3.1 Pedestrian Segment and Intersection LOS Example Cases

On the pedestrian LOS map, the LOS grade for pedestrian segment drops from a C to an E before and after the intersection with Haskell Road (see Figure 4.8).

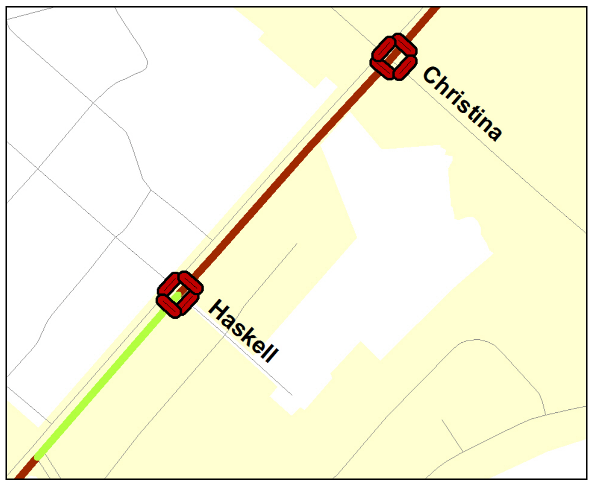

Figure 4.8 Pedestrian Segment LOS Score Change from C (light green) to E (red) (excerpt of Figure 4.5)

Many of the LOS factors were the same between these two segments, including traffic volume and speed limit. However, the presence, condition, and continuity of the sidewalk on each segment differed greatly, resulting in the divergent final LOS scores. The segment to the southwest of Haskell Rd. has a continuous sidewalk on one side of the road with a wide, grassy buffer and good pavement condition. The segment to the northwest of Haskell, however, only has a few sidewalked sections which present many barriers to pedestrian through-movement.

The sidewalk facility differences are what resulted in one segment receiving two LOS letter grades higher than the other. Figure 4.9 shows photos of the sidewalk facilities on these two different segments.

Figure 4.9 Route 2 sidewalk comparison. Left: continuous sidewalk with buffer located southwest of Haskell Road on Route 2; Right: discontinuous sidewalk located northeast of Haskell Road on Route 2

The intersection of Route 2 and Apple Road provides another interesting example of LOS score differences. Three of the four intersection sides have exactly the same LOS score, but the south leg of the intersection scored one letter grade higher than the others (see Figure 4.10)

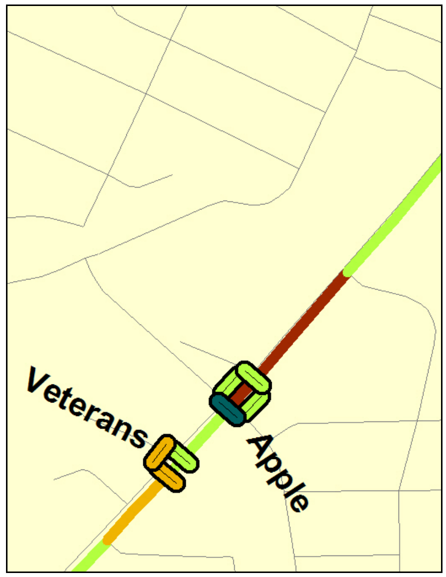

Figure 4.10 Pedestrian LOS Scores at Route 2/Apple Rd. Intersection (excerpt of Figure 4.5)

At this intersection, all four sides received the same point values for pedestrian crossing signal (with countdown), crosswalk presence, and curb at crossing point (with truncated domes). The south side of the intersection, however, received two extra points because there are no turning vehicle conflicts. On the south side, the pedestrian signal phase is offset from the left-turn signal given to traffic turning left onto Route 2. Additionally, traffic is not permitted to turn right on red from Apple Rd. onto Route 2. Because of these traffic signal characteristics, pedestrians crossing on the south side of this intersection would not encounter any turning vehicle conflicts, and this single fact earned the south intersection leg a higher LOS grade.

4.3.2 Bicycle Segment and Intersection LOS Example Cases

The bicycle LOS map shows that most segments along Route 2 scored relatively well for segment LOS. This is because the majority of Route 2 provides a striped bicycle lane on both sides of the road. The numerical scores for each bicycle segment vary slightly due to differences in pavement condition and barriers to through-movement, but the majority of segment scores fell into the "C" grade range. The major bicycle segment score change occurs at the portion of Route 2 as it approaches Main Street in Newark. At this point, the striped bicycle lane disappears and only a narrow shoulder takes its place. This results in the bicycle segment LOS score dropping from a C to a D. Figure 4.11 below shows the two types of bicycle facilities along Route 2 that earned different final LOS scores.

Figure 4.11 Route 2 bike lane comparison. Left: Continuous bike lane on Route 2; Right: Narrow shoulder on Route 2 near Main Street

Bicycle LOS scores at intersections in this study tended to vary with speed limit, traffic volume, and number of crossing lanes. The intersection of Route 2 and Route 4 (Christina Parkway) provides a good example of bicycle intersection LOS scoring (see Figures 4.12 and 4.13).

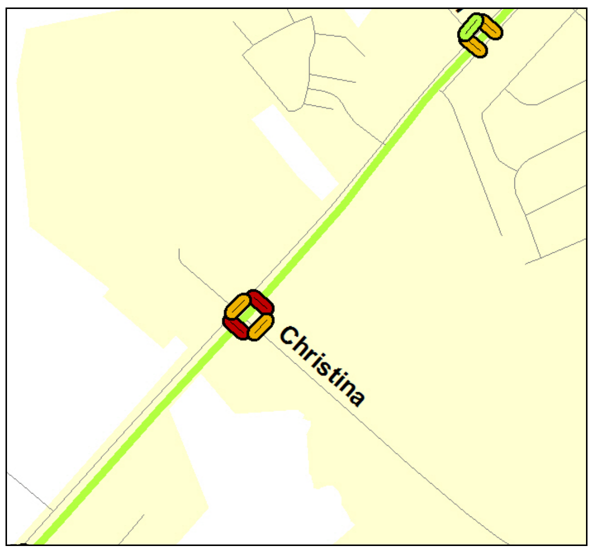

Figure 4.12 Bicycle Intersection LOS at Route 2/Route 4 Intersection (excerpt of Figure 4.6)

Figure 4.13 Route 2/Route 4 Intersection

By most accounts, the intersection of Route 2 and Route 4 is a threatening environment for both bicyclists and pedestrians. For this reason it may be surprising that two sides of this intersection received a score of D rather than E. The reason for this discrepancy in scores is due to the "crossing width" of the different sides of the intersection. For bicyclists traveling along Route 2 and crossing Route 4, the crossing width of the intersection is five lanes (worth one point on the index). For bicyclists traveling along Route 4 and crossing Route 2, the crossing width of the intersection is six lanes (worth zero points on the index) (see Figure 4.14). This small change in score was enough to bump two of the intersection sides from an E to a D. This small scoring difference represents the importance of recording each LOS factor score in a database so that the reason for each final LOS score can be traced.

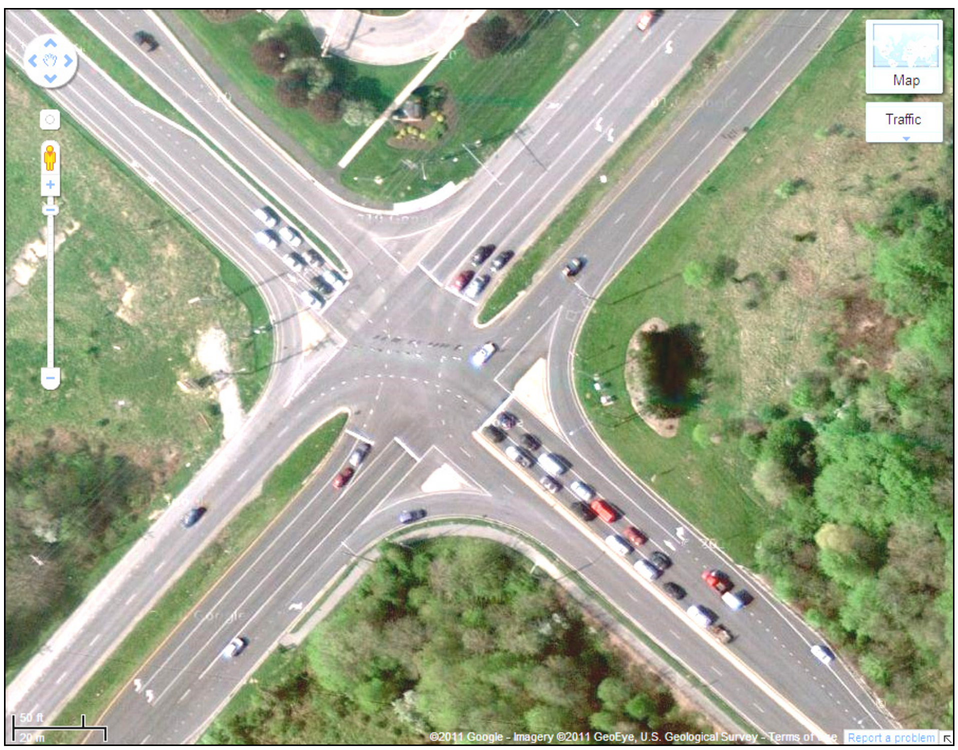

Figure 4.14 Intersection of Route 2 and Route 4, crossing width differences. Image Source: Google Maps

4.4 Data Collection, Analysis, and Mapping of LOS on Sample Road Segments in Elkton, MD

The town of Elkton, Maryland was chosen as the site of further LOS analysis largely because staff at WILMAPCO were engaged in a bicycle plan for the town. It was thought the present study could provide multimodal LOS scores for the Elkton Bicycle Plan, though this never ended up in the plan's scope. Nevertheless WILMAPCO staff already had a good level of familiarity with the town and provided the author with seven road segments with varying traffic and geometrical characteristics. One segment was discarded because of the lack of signalized intersections, resulting in six road segments for LOS analysis. These road segments are shown on the map in Figure 4.15.

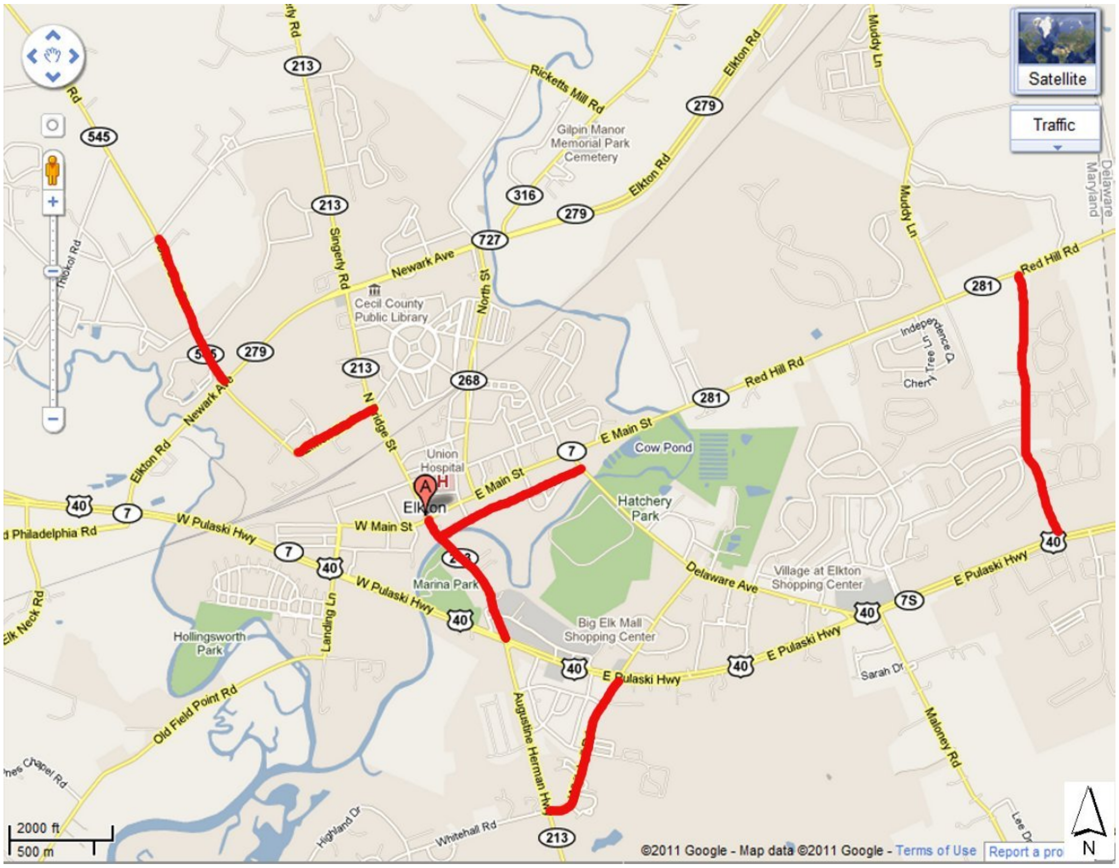

Figure 4.15 Road segments (in red) in Elkton, MD selected for LOS analysis. Image Source: Google Maps

For the Elkton study, segments were again generally defined as the stretch of roadway between two signalized intersections. However, as was the case in the Route 2 study, some segments end at non-signalized intersections in cases where the segment would have become too long for useful analysis or where the non-signalized intersection represents a significant change in road characteristics. The process of defining road segments and identifying signalized intersections for analysis in the Elkton study was performed using Google Maps "Street View" rather than a field visit. This method was much quicker than a field assessment and is recommended for further applications of these LOS indexes where possible, as Street View is not available everywhere. The resulting list of seven segments and ten intersections chosen for LOS analysis is shown in Figure 4.16.

Road Name	Segment Start/End	Length	Signalized Intersections
MD 545/Blue Ball Rd.	MD 279 to Dogwood Rd.	0.6 mile	MD 545/MD 279
Elkton Blvd.	MD 545 to MD 213	0.3 mile	Elkton Blvd/MD 213
MD 213/Bridge St.	Main St. to Howard St.	0.1 mile	MD 213/Main St.
MD 213/Bridge St.	Howard St. to US 40	0.5 mile	MD 213/Howard St. MD 213/US 40
Howard St.	MD 213 to MD 7	0.6 mile	Howard St/MD 7
Whitehall Rd.	MD 213 to US 40	0.6 mile	Whitehall/MD 213
Delancey Rd.	US 40 to MD 281	1.0 mile	Whitehall/US 40 Delancey Rd/US 40
			Delancey Rd/MD 281

Figure 4.16   Segment and intersection definitions for Elkton, MD LOS analysis

Field data for the road segments and intersection in Elkton, MD were collected on two different dates (September 3rd and September 10th, 2010). The author travelled to the town of Elkton by car with maps, field scoring sheets, a tape measure, and a camera. The author walked the length of each segment in both directions in order to evaluate each side of the roadway separately. As in the Route 2 study, the author also crossed each leg of each intersection in order to collect intersection field data. The data collection sheets for the Elkton, MD study were redesigned based on lessons learned from the Route 2 experience. These data collection sheets provide more space for writing notes about each index factor and provide separate sheets for each segment and intersection. An example of a scoring sheet used for field data collection in Elkton is shown in Figure 4.17.

	A	B	C	D	E	F	G	H	I	J
1	**MD545, 1N**									
2										
3	Side_Present	SP_Score	Side_Wid	SW_Score	Ped_Cr	PC_Score	Bike_Cr	BC_Score	Veh_Con	VC_Score
4										
5	AADT	AADT_Score	PSL	PSL_Score	Perc_Heavy	PH_Score	Side_Cond	SC_Score	Offset	Off_Score
6										
7	Medians	Med_Score	Trees	Tree_Score	Ben_Light	BL_Score	Slope	Slope_Score	W_Appeal	WA_Score
8										
9	Cross_Opp	CO_Sore	Ln_Width	LW_Score	Barriers	Bar_Score	Pav_Cond	PC_Score	B_Appeal	BA_Score
10										
11	Headway	Head_Score	Hours	Hour_Score	PLOS	PLOS_Score	Stop_Am	SA_Score	Interval	Int_Score
12										

Figure 4.17 Example Segment Field Data Collection Sheet for Elkton, MD

The remote data collection for segments and intersections in Elkton, MD was performed in much the same way as the data collection for the Route 2 study. Remote data sources were acquired from Maryland DOT, WILMAPCO-provided aerial photos and GIS files, and in some cases Google Maps and Google Earth. Details about the source and methodology for remotely-collected data are included in Appendix D. Once all of the remote data were gathered, the data values and index points for each segment and intersection leg were combined into one Excel spreadsheet. Examples of the segment and intersection scoring files in Excel are shown in Figures 4.18 and 4.19. The Excel file was also used to calculate the total numerical score and converted letter grade LOS for each segment and intersection, as shown in Figure 4.20.

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Route_ID	Seg_ID	Side_Present	SP_Score	Side_Wid	SW_Score	Ped_Cr	PC_Score	Bike_Cr	BC_Score	Veh_Con	VC_Score	AADT	AADT_Score	PSL	PSL_Score
MD545	1N	Non-existent	0	Non-existent	0	N/A	0	N/A	0	<15	2	5340	2	40 mph	0.5
Elkton	1E	Non-existent	0	Non-existent	0	N/A	0	N/A	0	15-30	1	4525	2	40 mph	0.5
Howard	1E	< 50%	1	4.5 ft.	1	N/A	0	N/A	0	<15	2	6898	2	25 mph	2
Delancy	1N	< 50%, but continuous	1	4.5 ft.	1	N/A	0	N/A	0	<15	2	11,020	1	35 mph	1
Whitehall	1E	Present < 50% of segment, but continuous next to school and assisted living	1	4.5-5	1	N/A	0	N/A	0	<15	2	3675	2	25 mph	2
MD213	1N	Continuous >50% segment	3	4 ft.	1	N/A	0	N/A	0	15-30	1	18520	1	35 mph	1
MD213	2N	Non-existent	0	Non-existent	0	N/A	0	N/A	0	App. 15	1	18520	1	25 mph	2

Figure 4.18 Example Segment Scoring Microsoft Excel Sheet for Elkton, MD

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Route_ID	Int_ID	Stable_Id	Direction	Ped_Signal	PS_Score	Curb	Curb_Score	Crosswalk	CW_Score	Median	Med_Score	PSL	PSL_Score	PSL_Bk_Score	AADT
MD545	MD279	0	N	None	0	None	0	None	0	None	0	40 mph	0.5	0	5340
MD545	MD279	1	S	None	0	None	0	None	0	None	0	40 mph	0.5	0	5340
MD545	MD279	2	E	None	0	None	0	None	0	None	0	50 mph	0	1	10192
MD545	MD279	3	W	None	0	None	0	None	0	None	0	50 mph	0	1	10192
Elkton	MD213	4	N	None	0	None	0	None	0	None	0	30 mph	1	1	18520
Elkton	MD213	5	S	None (see pic)	0	None	0	None	0	None	0	30 mph	1	1	18520
Elkton	MD213	6	E	None	0	None	0	None	0	None	0	40 mph	0.5	2	4525
Elkton	MD213	7	W	None	0	None	0	None	0	None	0	40 mph	0.5	2	4525
Howard	MD213	8	N	None	0	None	0	None	0	None	0	25 mph	2	3	18980
Howard	MD213	9	S	None	0	None	0	None	0	None	0	25 mph	2	Null	18980
Howard	MD213	10	E	None	0	None	0	None	0	None	0	25 mph	2	3	6898
Howard	MD213	11	W	No Crossing	Null	Null	Null	Null	Null	Null	Null	Null	Null	Null	6898
Howard	MD7	12	N	None	0	None	0	None	0	None	0	25 mph	2	Null	7757
Howard	MD7	13	S	None	0	None	0	None	0	None	0	25 mph	2	3	7757
Howard	MD7	14	E	Null	Null	Null	Null	Null	Null	Null	Null	25 mph	Null	3	6898
Howard	MD7	15	W	None	0	None	0	None	0	None	0	25 mph	2	3	6898
Delancy	MD281	16	N	Null	Null	Null	Null	Null	Null	Null	Null	35 mph	Null	0	11020
Delancy	MD281	17	S	None	0	None	0	None	0	None	0	35 mph	1	0	11020
Delancy	MD281	18	E	None	0	None	0	None	0	None	0	50 mph	0	1	6680
Delancy	MD281	19	W	None	0	None	0	None	0	None	0	50 mph	0	Null	6680

Figure 4.19 Example Intersection Scoring Microsoft Excel Sheet for Elkton, MD

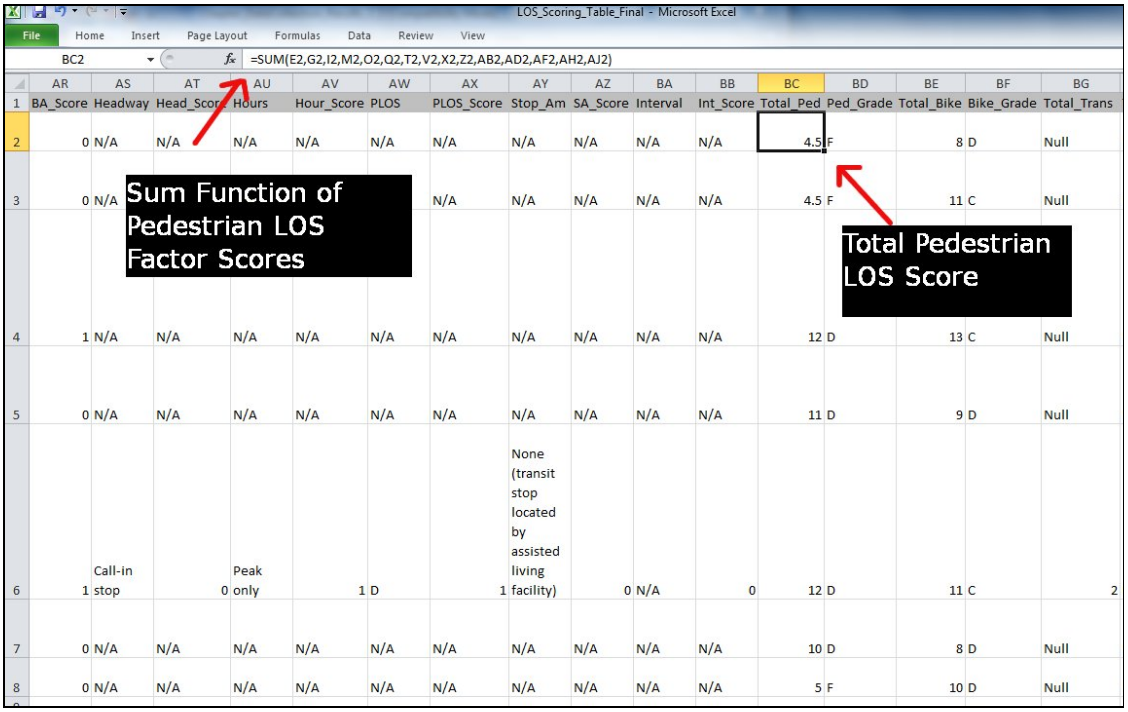

Figure 4.20 Example Excel Calculation of Total Segment LOS Scores

In order to represent the resulting LOS scores geographically, shapefiles for the road segments and intersections of interest were created in ArcGIS. (It should be noted here that transit LOS was never fully mapped due to limitations encountered in the implementation of the transit LOS index. Transit LOS is addressed in a later section). To create the road segment shapefiles, the ArcGIS editing tools were used to modify (shorten or lengthen) existing road segments from the Maryland DOT road file. In ArcGIS, this proved easier than creating road segments from scratch, as was done in the Route 2 study. By creating a selection of these modified Maryland DOT road segments, a new shapefile was created that included only the Elkton, MD study segments. Because both sides of the roadway were evaluated and scored individually for this study, two shapefiles were created so that there were two lines representing each road segment. This was achieved by making a copy of the original Elkton road segments shapefile and offsetting one of the files by about twenty feet. The resulting two segment shapefiles represent "northbound" and "eastbound" segments on one shapefile and "southbound" and "westbound" segments on the other shapefile (see Figure 4.21).

The shapefile for intersections was created as a point layer from scratch. Four points were created around each intersection location, even if some of these points would eventually be a "null" score because of invalid crossing locations. In each of the shapefiles, a verbal segment or intersection ID and ID number were assigned to each segment or intersection leg in the attribute table. After assigning an ID number to each segment or intersection leg in the GIS file, the same ID number was added to the Microsoft Excel scoring sheets. This "unique identifier" allowed the Excel tables to be joined to each shapefile's attribute table, resulting in an attribute table for each segment and intersection leg that includes the data values and scores for each index item. The attribute tables also already included final LOS scores and grades since these were previously calculated in Excel. Example attribute tables from the Elkton, MD GIS files are shown in Figures 4.22 and 4.23.

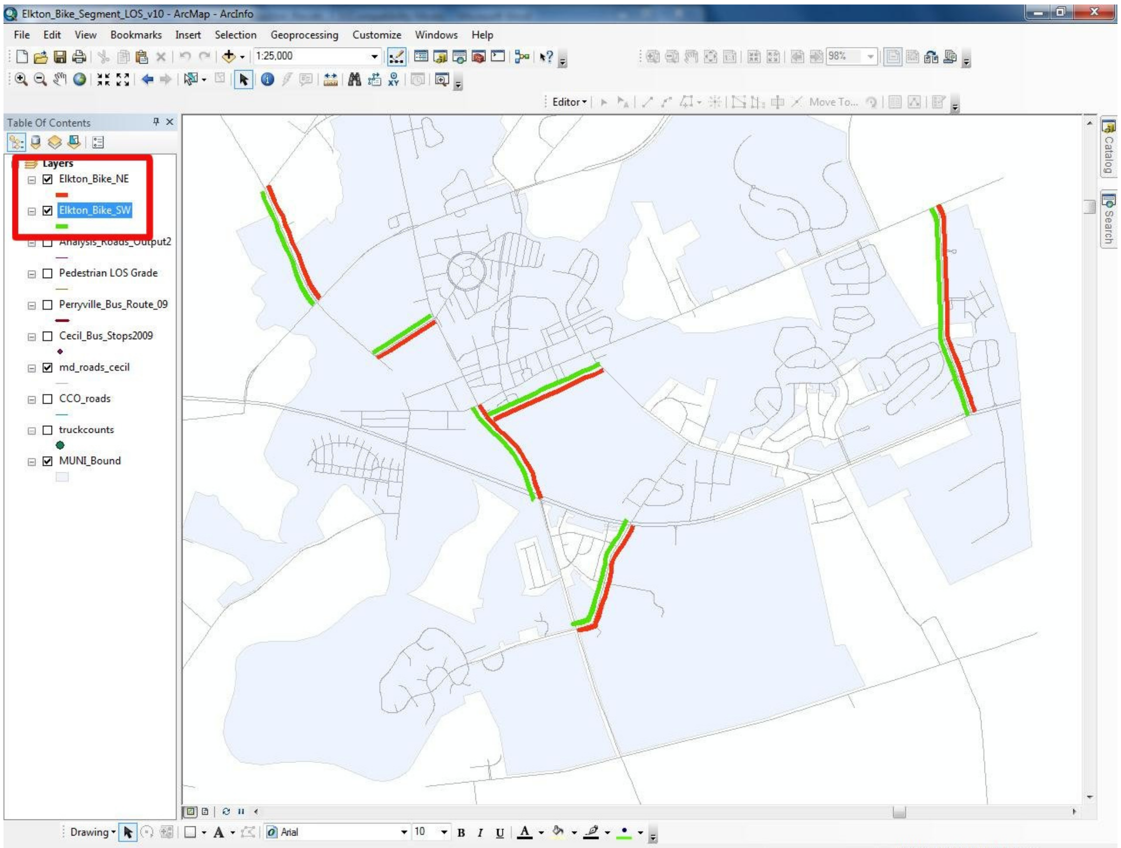

Figure 4.21 Elkton, MD LOS Shapefiles: “North/East” shapefile (red) and “South/West” shapefile (green). Image source: ArcGIS screenshot

Elkton_Ped_SW

FID_1	Route_ID	Seg_ID	Side_Prese	SP_Score	Side_Wid	SW_Score
0	Whitehall	lW	< 50%	1	4 ft.	1
1	MD213	1S	Continuous <50% segment	1	4.5 ft.	1
2	MD545	1S	Non-existent	0	Non-existent	0
3	Howard	1W	< 50% (very discontinuous)	1	4 ft.	1
4	Elkton	1W	Non-existent	0	Non-existent	0
5	Delancy	1S	Non-existent	0	Non-existent	0
6	MD213	2S	Continuous (except parking lot intrusion)	6	4.5 ft.	1

Figure 4.22 Elkton Segment LOS ArcGIS Attribute Table Example

LOS_Ped_Intersections

Stable_ID	Route_ID	Int_ID	Stable_Id	Direction	Ped_Signal	PS_Score	Curb	Curb_Score	Crosswalk
9	Howard	MD213	9	S	None	0	None	0	None
10	Howard	MD213	10	E	None	0	None	0	None
12	Howard	MD7	12	N	None	0	None	0	None
13	Howard	MD7	13	S	None	0	None	0	None
15	Howard	MD7	15	W	None	0	None	0	None
17	Delancy	MD281	17	S	None	0	None	0	None
18	Delancy	MD281	18	E	None	0	None	0	None
19	Delancy	MD281	19	W	None	0	None	0	None
20	Delancy	Pulasky	20	N	None	0	None	0	None
21	Delancy	Pulasky	21	S	ADA, Countdown	3	ADA, Truncated Domes	2	Yes
22	Delancy	Pulasky	22	E	None	0	None	0	None
23	Delancy	Pulasky	23	W	ADA, Countdown	3	ADA, Truncated Domes	2	Yes
24	MD213	US40	24	N	None	0	None	0	None
25	MD213	US40	25	S	None	0	None	0	None
26	MD213	US40	26	E	None	0	None	0	None
27	MD213	US40	27	W	None	0	None	0	None
28	MD213	MD7	28	N	Countdown, ADA	3	ADA, bulbout, domes	3	Marked
29	MD213	MD7	29	S	None	0	Acceptable curb cut	1	None
30	MD213	MD7	30	E	None	0	ADA, bulbout, domes	3	Marked
31	MD213	MD7	31	W	Countdown, ADA	3	ADA, bulbout, domes	3	Marked
32	Whitehall	MD213	32	N	None	0	None	0	None
33	Whitehall	MD213	33	S	None	0	None	0	None

Figure 4.23 Elkton Intersection LOS ArcGIS Attribute Table Example

Once the attribute tables for each segment and intersection were complete, the total LOS letter grade field was used to symbolize each segment and intersection feature. The LOS letter grade color scheme used in these maps is roughly the same as the color scheme used in the Route 2 maps. While the Route 2 study resulted in two maps, the Elkton, MD study resulted in four final maps: one each for pedestrian segment LOS, pedestrian intersection LOS, bicycle segment LOS, and bicycle intersection LOS. The segment and intersection maps were produced separately for the sake of improved visual representation. Because the Elkton maps represent two lines for each road segment, and the maps also represent intersection legs with points instead of lines (a limitation of ArcGIS point file options), the result of representing the segment LOS and intersection LOS on the same map presented clarity issues. The final pedestrian and bicycle segment and intersection LOS maps are shown in Figures 4.24 through 4.27.

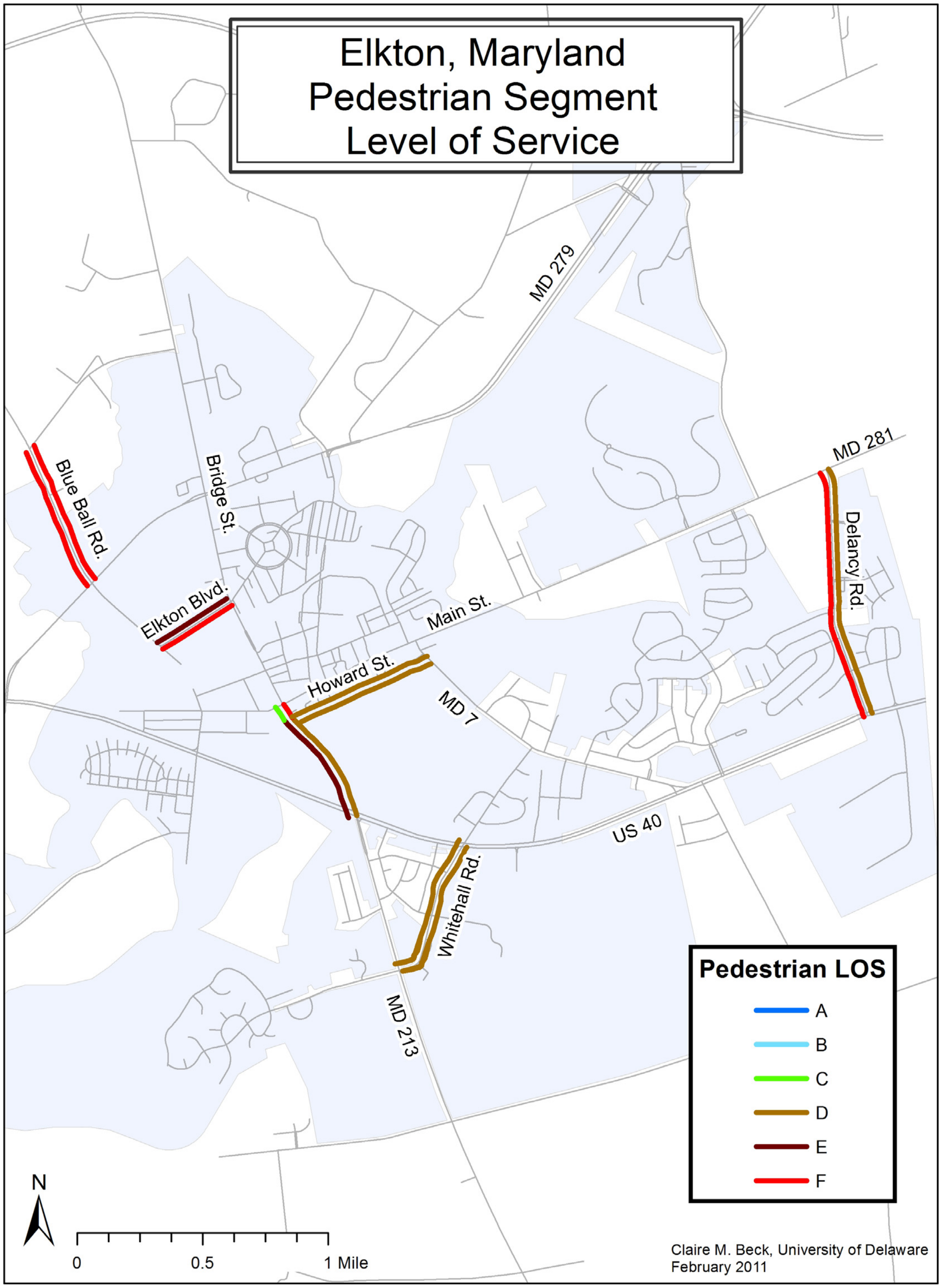

Figure 4.24 Pedestrian Segment LOS Map, Elkton, MD

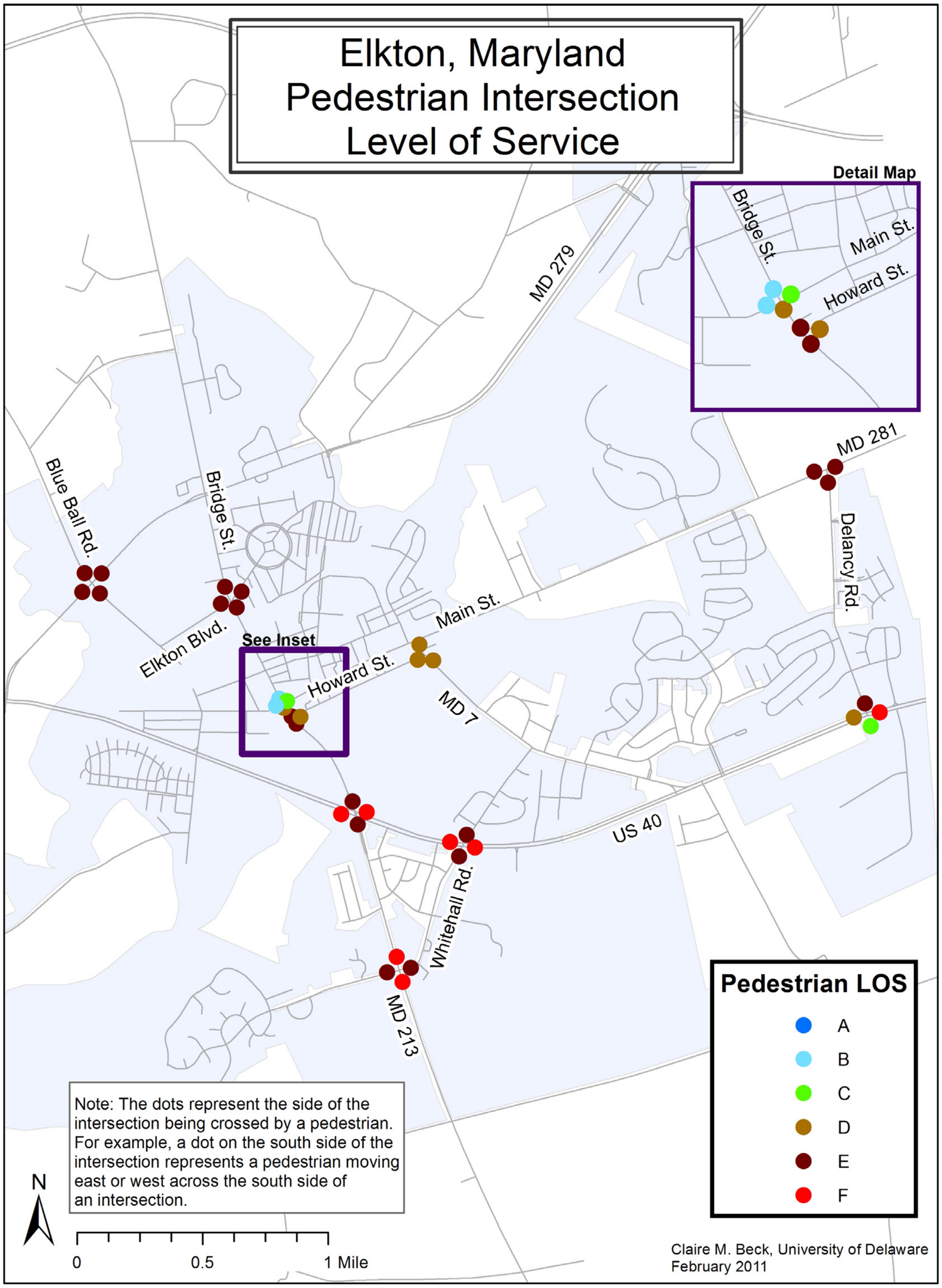

Figure 4.25 Pedestrian Intersection LOS Map, Elkton, MD

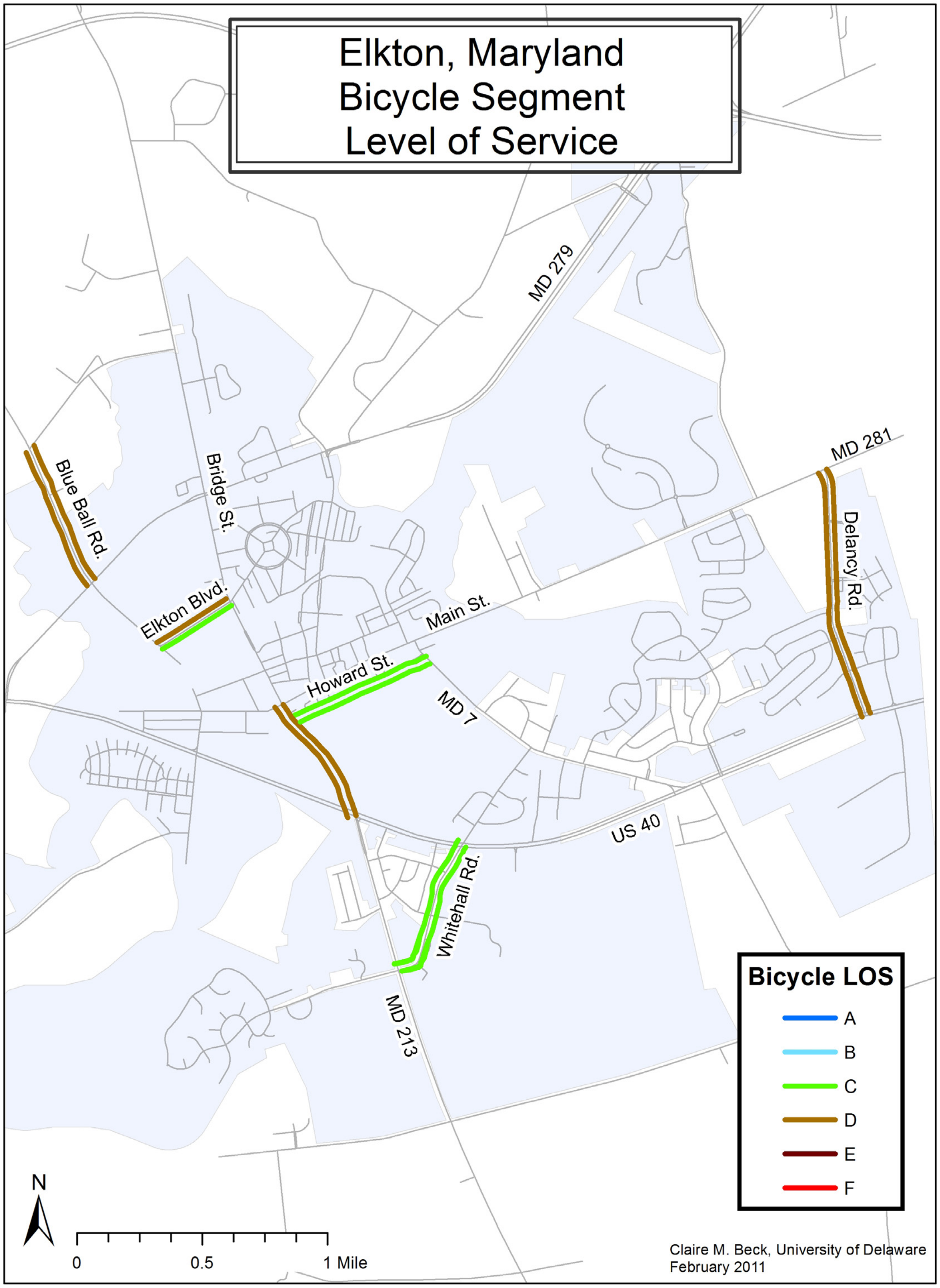

Figure 4.26 Bicycle Segment LOS Map, Elkton, MD

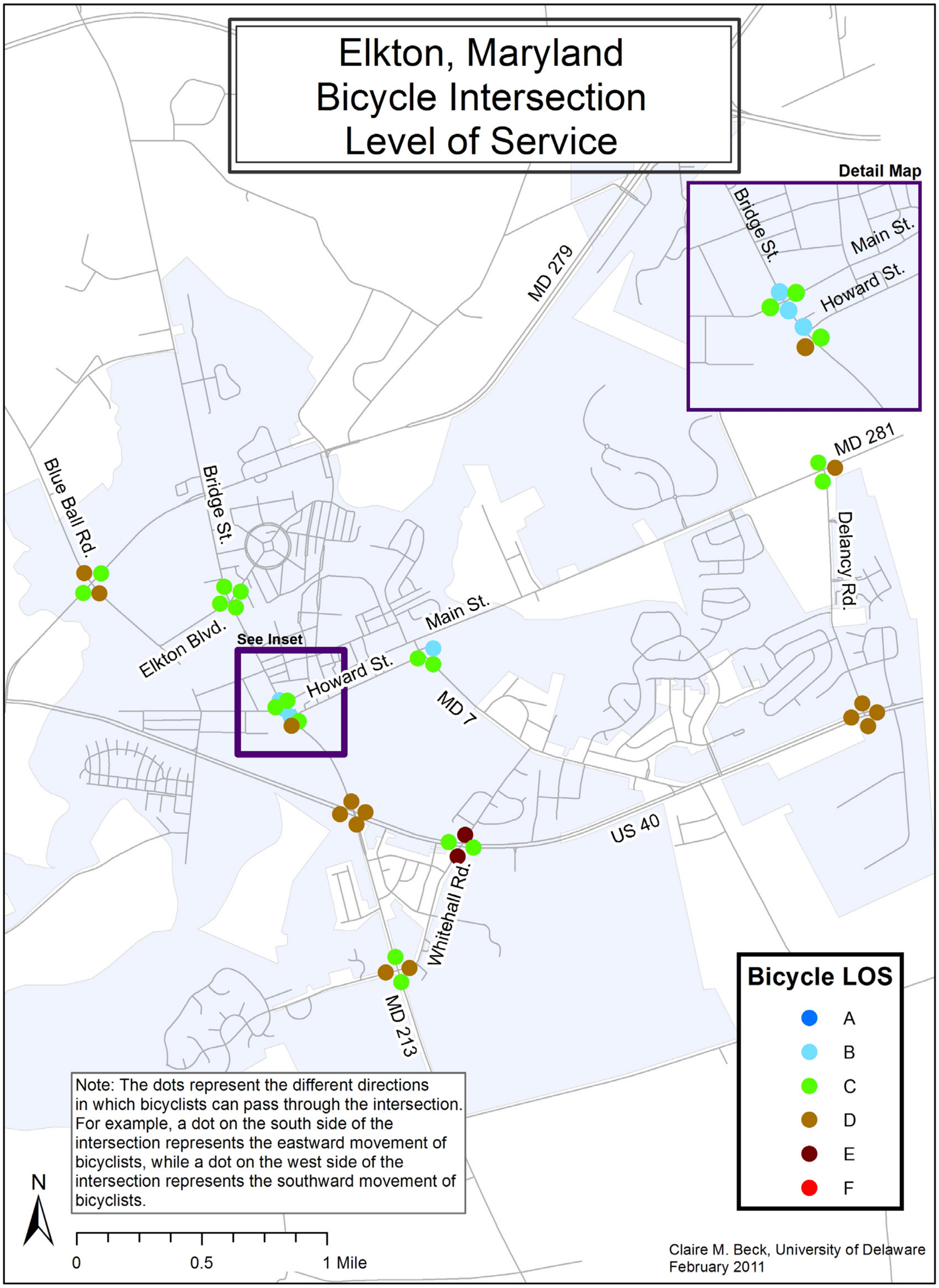

Figure 4.27 Bicycle Intersection LOS Map, Elkton, MD

A formal transit LOS map was not produced for this study. While the transit LOS index was applied to the analysis segments in Elkton, only two transit stops were located during the field visit, and one additional transit stop was identified on the Cecil County bus service's published route map (three bus stop locations shown in Figure 4.28). In the case of the bus stops located on Elkton Boulevard and Whitehall Road, according to the bus service's published schedules, these locations are not regularly scheduled bus stops. Instead, bus patrons have the ability to call ahead and request a stop at that particular location. The researcher decided that call-in service in essence presents a poor transit headway because potential patrons would have to have previous knowledge of the service and plan for it in advance of their trip. A bus stop that only receives transit service in response to a call is likely less convenient than a regularly-scheduled bus stop with infrequent service. Thus, these two bus stops received an automatic score of zero on the "average headway" index factor.

The bus stop on Bridge Street/MD 213, according to the published schedules, is indeed a regularly-scheduled bus stop. This stop is located at a dialysis center in a shopping strip, and the headways (time between bus arrivals) are over an hour throughout the day. Because the headway is over an hour, this bus stop also received a zero for the "average headway" factor. For all three bus stops, the hours of service are peak hours only, with somewhat concentrated service in the mornings and early evenings and infrequent service during mid-day. These service hour characteristics earned all three stops a low score for the "hours of service" factor. In total, considering the limited service frequency and hours of service for the three bus stops, as well as the lack of transit stop amenities, all three bus stops identified in the

Elkton study area received a total LOS grade of E. Overall, the implementation and results of the transit LOS index in Elkton were not very successful, and there are some lessons to be learned from this experience. Analysis of the transit LOS index and recommendations for future work are included in the conclusion chapter.

Figure 4.28 Bus Stop Locations on Elkton, MD Road Segments

4.5 Results of LOS Analysis in Elkton, MD

The resulting LOS scores for the road segments and intersections in Elkton show a fair degree of variation. The pedestrian LOS scores vary more in general than bicycle LOS, and the intersection LOS scores vary more than the segments. The frequency of each segment and intersection score for pedestrian and bicycle LOS is represented graphically in Figure 4.29. At a broad level, the pedestrian LOS scores for the study areas in Elkton are worse than the bicycle LOS scores. Many of the pedestrian segments and intersections received poor LOS scores due to the lack of sidewalks and crosswalks. Many of the bicycle segments and intersections received mediocre scores even without the presence of bicycle lanes, largely because bicycle LOS is most strongly influenced by traffic volumes and speeds. In order to more specifically examine the reasons for particular segment and intersection scores, a few examples of individual pedestrian and bicycle segments and intersections are explored in the following sections.

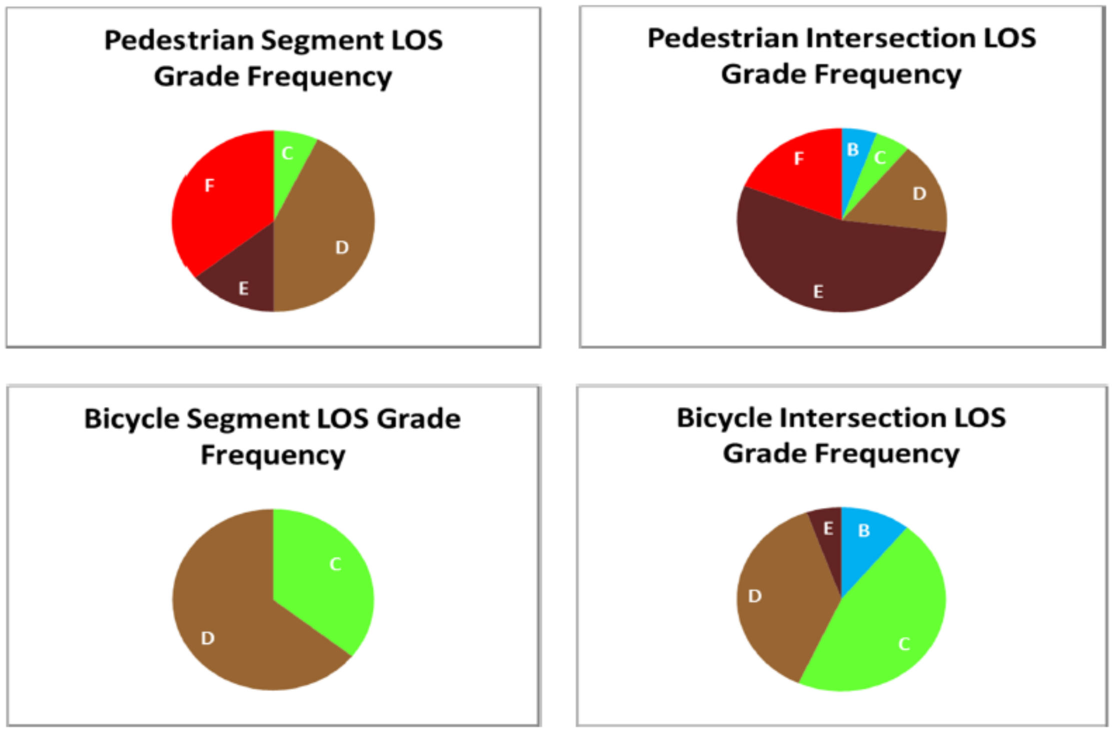

Figure 4.29 LOS Grade Frequencies in Elkton, MD

4.5.1 Pedestrian Segment and Intersection LOS Example Cases for Elkton, MD

Two pedestrian segments in the Elkton, MD study are of particular interest because of the likelihood of pedestrian trips along the roadway. Bridge Street/MD 213 is a four-lane highway lined with commercial and office land uses. Because of the density of services along this roadway as well as its proximity to Elkton's downtown area, the segment of Bridge Street between Main Street and

Pulaski Highway/US 40 is a viable area for utilitarian pedestrian trips. This section of Bridge Street is divided into two segments because of the signalized intersection at Howard Street, but this example focuses on the segment of Bridge Street extending south from Howard (see Figure 4.30).

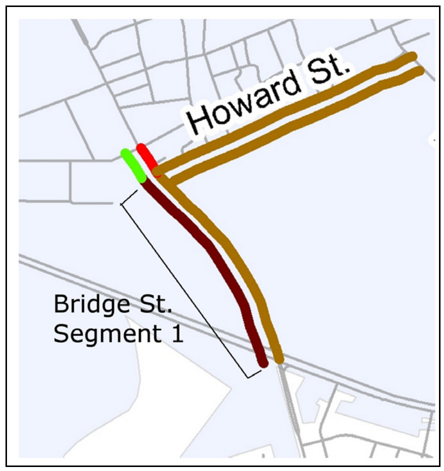

Figure 4.30 Pedestrian segment LOS on Bridge St. Example segment south of Howard St. (excerpt of Figure 4.24)

The northbound side of Bridge Street received a final pedestrian LOS score of D, while the southbound side of the street received a score of E. Both sides of the segment received similar scores for traffic volume and speed, percent heavy vehicles, and potential vehicle conflicts (which were somewhat numerous due to the frequency of commercial driveways). The two sides received different scores, however, for sidewalk presence and continuity. The northbound side of the Bridge Street segment possesses an almost continuous sidewalk facility with proper curb cuts and few barriers. The southbound side, however, only possesses a sidewalk facility that is continuous for less than 50% of the segment length and is missing some curb cuts. These differences in sidewalk facilities are what resulted in different scores for each side of the segment. Photos of the sidewalk facility characteristics on both sides of the Bridge Street segment are shown in Figure 4.31.

Figure 4.31 Bridge St. sidewalk comparison. Left: Bridge Street northbound in Elkton, MD with continuous sidewalk and proper curb cuts at driveways; Right: Bridge Street southbound in Elkton, MD with discontinuous sidewalk

The segment along Whitehall Road is another interesting example of pedestrian LOS in an area with high pedestrian activity potential. The portion of Whitehall Road examined in this falls within a residential area passing by an assisted living facility, a rehab center, and an elementary school. The majority of the segment length, up until Whitehall Road approaches Pulaski Highway/US 40, is a quiet road that could be a very pleasant walking environment. However, decent pedestrian facilities are only provided in front of the school and the assisted living facility, and the sidewalks become discontinuous and poorly maintained along the neighborhood portion of the road (see Figure 4.32). Both sides of the Whitehall Road segment received a pedestrian LOS score of D. The segment earned low factor scores for the sidewalk discontinuity, but the overall LOS score for Whitehall Road was buoyed by the road's low AADT, low speed limit, and small number of potential vehicle conflicts.

Figure 4.32 Walking facilities along Whitehall Rd. near the assisted living center, the elementary school, and the neighborhood area. Image sources: Google Maps and Claire M. Beck

The majority of the intersections in the Elkton, MD study provided no pedestrian crossing facilities at all. In fact, the only intersections with marked crosswalks and pedestrian crossing signals are the Bridge St./Main St. intersection and the Delancy Rd./Pulaski Highway intersection. The intersection of Delancy Road and Pulaski Highway/US 40 is an interesting test case for the pedestrian intersection LOS index because it presents a variety of pedestrian facilities and traffic conditions. This resulted in four different LOS scores for each leg of the intersection (see Figure 4.33).

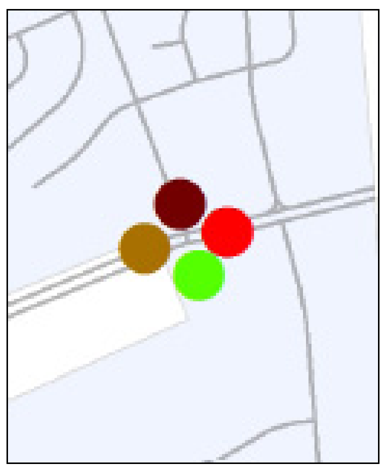

Figure 4.33 Pedestrian Intersection LOS scores at the intersection of Delancy Road (extending north) and Pulaski Highway (running east to west) (excerpt of Figure 4.25)

At Delancy/US 40, marked crosswalks and pedestrian crossing signals are only provided on the west and south side of the intersection. These two crossings provide both ADA-accessible curb cuts (including truncated domes) and ADA-accessible pedestrian signals with countdown mechanisms. The east and north sides of the intersection, however, do not provide crosswalks or crossing signals. These differences in pedestrian crossing facilities, as well as differences in traffic volume and posted speed limit, are what contribute to the four different LOS scores on each side of the intersection. This intersection also features pedestrian accommodations at its two right-turn channelization islands, which can help ease turning vehicle conflicts at those points. Figure 4.34 shows the score sheet for each side of this intersection, which demonstrates the differences in individual factor scores as well as what contributed to those scores. Figures 4.35 through 4.38 show pictures of this intersection taken during the field visit.

RouteID	IntID	Dir	PedSignal	PSScore	Curb	CurbScore	CWalk	CWScore	Median	MedScore
Delancy	Pulasky	N	None	0	None	0	None	0	None	0
Delancy	Pulasky	S	ADA, Countdown	3	ADA, Truncated Domes	2	Yes	1	Present	1
Delancy	Pulasky	E	None	0	None	0	None	0	Present	1
Delancy	Pulasky	W	ADA, Countdown	3	ADA, Truncated Domes	2	Yes	1	Present	1

Dir	PSL	PSL_Score	AADT	AADTScore	Turn_Veh	TVScore	Width	WdthScore	Total_Ped	Ped_Grade
N	35 mph	1	11020	1	RTOR Allowed	0	4 lanes	1	3	E
S	35 mph	1	11020	1	No Conflict due to Porkchop	1	4 lanes	1	11	C
E	55 mph	0	28213	0.5	RTOR Allowed	0	6 lanes	0	1.5	F
W	55 mph	0	28213	0.5	RTOR Allowed	0	6 lanes	0	7.5	D

Figure 4.34 Pedestrian Intersection LOS score chart for Delancy Rd./US 40 intersection

Figure 4.35 Delancy Rd./US 40 intersection, looking south

Figure 4.36 Pedestrian crossing signal activation button on west side of Delancy Rd./US 40 intersection

Figure 4.37 Crosswalk and countdown signal on west side of Delancy Rd./US 40 intersection

Figure 4.38 Crosswalk and curb cut implementation at right-turn channelization islands on south and west sides of Delancy Rd./US 40 intersection

4.5.2 Bicycle Segment and Intersection LOS Example Cases for Elkton, MD

All of the analysis segments in Elkton received a grade of either C or D for bicycle segment LOS. None of the roadways examined included a marked bicycle lane, but there were important differences in lane widths, which contribute significantly to a segment's score. Differences in traffic speed, traffic volume, and barriers (in the form of varying shoulder widths) also contributed to variations in LOS scores. A comparison of two particular road segments—MD 545/Blue Ball Road and Howard Street—provides a good example of the road conditions that can contribute to differing bicycle segment LOS scores. The bicycle segment scores for these two roadways are shown in Figure 4.39.

RouteID	Seg_ID	Veh_Con	VC_Score	AADT	AADTScore	PSL	PSLBkScore	PercHeav	PH_Score	Medians	MedScore
Howard	1E	<15	2	6898	2	25 mph	3	4%*	1	None	0
Howard	1W	15-30	1	6898	2	25 mph	3	4%*	1	None	0
MD545	1N	<15	2	5340	2	40 mph	1	6.20%	0	None	0
MD545	1S	<15	2	5340	2	40 mph	1	6.20%	0	None	0

RouteID	Seg_ID	LnWidth	LWScore	Barriers	BarScore	PavCond	PCScore	BAppeal	BAScore	Total_Bike	Bike_Grade
Howard	1E	12 or less	0	Free of barriers	2	Excellent	2	Good	1	13	C
Howard	1W	12 ft.	0	Free of barriers	2	Excellent	2	Good	1	12	C
MD545	1N	14 ft.	1	Largely free	1	Fair	1	Unpleasant	0	8	D
MD545	1S	>14 ft.	3	Largely free	1	Fair	1	Unpleasant	0	10	D

Figure 4.39 Comparison table of bicycle LOS segment scores for MD 545/Blue Ball Rd. and Howard St.

Both directions of MD 545/Blue Ball Road received a final LOS grade of D, whereas both directions of Howard Street received a grade of C. The comparison table above shows that the scoring differences between these two roadways are due to several factors, including the posted speed limit, the percentage of heavy vehicles, the width of the outside lane, the presence of barriers, and the bicycling appeal of the roadway environment. The scoring differences in these roadway characteristics fairly accurately represent the real-life differences in these roadways that one would notice during a field visit. MD 545/Blue Ball Road is a two-lane, high-speed road with wide shoulders and significant truck traffic that passes through industrial areas. Howard

Street, on the other hand, is a narrow road with low speeds near the town's downtown area that passes through mostly civic and residential uses.

By most accounts, Howard Street is a fairly pleasant and safe road for bicycling due to its low vehicle speeds and surrounding uses. However, the main reason that this roadway received a grade of C is because of the narrow lane widths, which make it more difficult for cyclists and motorists to share the roadway. While Blue Ball Road is a higher speed roadway with heavy truck traffic, the presence of a fairly wide shoulder along the majority of the roadway provides at least marginal space for bicyclists to feel safe sharing the roadway with motorists. Figures 4.40 and 4.41 show pictures of the various conditions on these two roadways.

Figure 4.40 MD 545 shoulder examples. Left: MD 545 southbound shoulder; Right: MD 545 shoulder narrows at bridge (barrier to through-movement)

Figure 4.41 Howard St. shoulder examples. Left: Residential portion of Howard Street; Right: Commercial/civic portion of Howard Street

The bicycle intersection LOS scores show more variation than the bicycle segments, and it is clear from the data that traffic volume and traffic speed are what most significantly affect the scores of an intersection. None of the intersections examined provided a bike lane on the intersection approach, and all of the intersections provided a satisfactorily wide outside through-lane. The intersection of Whitehall Road and Pulaski Highway/US 40 is a perfect example of the importance of traffic speed and volume to bicycle intersection LOS. Whitehall Road is a very low speed and low volume residential arterial, whereas US 40 is a regional arterial with high traffic volumes and a high posted speed limit. The bicycle intersection LOS index is set up so that the speed and volume of the roadway upon which the bicyclist is riding are the data of interest. Thus, bicyclists riding on Whitehall Road through the intersection will experience a better LOS (grade C) than bicyclists riding on US 40 through the intersection (grade E). Figure 4.42 shows the bicycle intersection LOS scoring table for this intersection, and Figure 4.43 shows a picture of the intersection from the field visit.

Route_ID	Int_ID	Dir	PSL	PSLScore	AADT	AADTScore	C_Width	CWScore	LnWidth
Whitehall	US40	N	25 mph	0	3675	0	3 lanes	1	>14
Whitehall	US40	S	25 mph	0	3675	0	3 lanes	1	>14
Whitehall	US40	E	55 mph	3	30803	2	6 lanes	0	>14
Whitehall	US40	W	55 mph	3	30803	2	6 lanes	0	>14
Route_ID	**Int_ID**	**Dir**	**LWScore**	**Bk_Ln**	**BL_Score**	**RTOR**	**RTScore**	**Total_Bike**	**Bike_Grade**
Whitehall	US40	N	2	None	0	Allowed	0	3	E
Whitehall	US40	S	2	None	0	Allowed	0	3	E
Whitehall	US40	E	2	None	0	Allowed	0	7	C
Whitehall	US40	W	2	None	0	Allowed	0	7	C

Figure 4.42 Bicycle intersection LOS scoring chart for Whitehall Rd./US 40 intersection

Figure 4.43 Intersection of Whitehall Rd. and US 40 from perspective of Whitehall Rd. approach

4.6 Conclusion

The process of implementing the multimodal LOS indexes through data collection, field visits, and mapping exercises was an extremely valuable learning experience and will inform future improved studies. Overall, the resulting LOS scores for the analyzed segments and intersections were in line with the expectations of the project team. For example, because of the suburban nature of Route 2 and Elkton, generally low LOS grades (C or lower) were expected and found. In particular locations where pedestrian or bicycle accommodations had been implemented (such as intersections with crosswalk and pedestrian signal installations), LOS scores were slightly higher, as the researchers expected. During the Elkton study the LOS indexes should have been tested on roadways that would be expected to receive either very high (A) or very low (F) LOS grades. Evaluating LOS on road segments and intersections that are perceived as ideal for bicyclists and pedestrians, as well as areas that are perceived as dangerous and unaccommodating of bicyclists and pedestrians, would be an obvious future test for the extreme ends of the bicycle and pedestrian LOS indexes.

The data collection, analysis, and mapping processes for multimodal LOS were ultimately successful, but the experience provided several examples of what could be done better in the future and what deserves further research and exploration. Reflections on the project process, suggestions for further research, and overall conclusions are addressed in the following chapter.

Chapter 5

CONCLUSION

This multimodal LOS project consisted of several stages that occurred over the course of a year. The project involved an extensive literature review, several meetings with the project team and other interested parties, several versions of LOS index methodologies, field data collection, remote data collection and processing, analysis of data and photographs, and mapping and visualization using GIS software. Throughout the entire process, members of the project team—especially the author—encountered various roadblocks and methodology limitations that served as valuable learning experiences. This conclusion chapter will reflect on the multimodal LOS project by addressing three general themes: lessons learned from the project process; suggestions for further research; and the place of multimodal LOS in the larger context of transportation issues.

5.1 Lessons Learned

The major takeaway from the development and implementation of this project is that these multimodal LOS indexes are not feasible for large-scale applications. The fact that some of the index factors—such as curb ramp presence, transit stop amenities, and pedestrian crossing signals—require careful and time-consuming data collection makes these indexes largely impractical for implementation on a citywide or statewide scale. While the mathematical LOS models described in the literature review chapters seemed to be missing some factors that the project team deemed important, those methodologies are clearly intended to be practical for large-scale and repeated implementation by departments of transportation, metropolitan planning organizations, or other transportation planning agencies. The LOS index methodology developed for this project, however, is better suited for small-scale implementation such as area studies or neighborhood audits.

There are a few modifications to this index methodology that could make it easier to implement and minimize the amount of required field-collected data. Technologies such as Google Maps, Google Earth, Bing Maps, and high-quality aerial photos could possibly be used to collect some data that was collected in the field for this project. The following index factors could probably be easily measured using these technologies: presence of sidewalk; width of sidewalk; posted speed limit; sidewalk offset/buffer; presence and visibility of marked crosswalks; bike lane on intersection approach; and bicycle barriers to through-movement. An important limitation of these technologies, however, is that satellite and aerial imagery is often a year of more out-of-date, and aerial photos and Street View can be too blurry for meaningful analysis. Nonetheless, several index factors would still require a field visit, including: barriers (such as missing curb ramps) in the sidewalk facility; sidewalk pavement condition; cross slope of driveways; street trees/benches/pedestrian-scale lighting; bicycle facility pavement condition; pedestrian crossing signals; curb ramps at intersections; turning vehicle conflicts at intersections; and overall walking and bicycling appeal.

One approach to solving the problem of data that can only be collected in the field is to provide default values/scores or estimation procedures for index factors when the data cannot be easily obtained. The “Complete Streets LOS” software does this for items such as pavement condition, on-street parking occupancy, and traffic signal cycle lengths (Dowling Associates 2010). This method of default or estimated values only works for factors that are relatively stable throughout the area or contribute little to the overall LOS score. In the case of curb ramps and pedestrian crossing signals—factors that the project team believed to be important—this methodology would not be satisfactory.

While the data collection requirements may be a drawback for wide application, the major merit of this project's multimodal LOS methodology is that it has the potential to result in detailed recommendations for future LOS improvements. Like a neighborhood walkability or bikeability audit, the process of collecting field data, taking photographs, and otherwise thoroughly analyzing the roadways of interest acquaints the researcher(s) with on-the-ground conditions. These processes also document exactly what roadway or facility conditions are contributing negatively to the LOS score. While it is beyond the scope of this paper to make policy and engineering recommendations for the analysis areas, it is completely possible that the results of this project's sample LOS analysis could be used to describe specific recommendations. For example, the Elkton LOS study results would likely conclude suggestions such as, "closing the sidewalk gap between point A and point B on Bridge Street would significantly improve pedestrian segment LOS." The data, field experience, and photographs obtained during the implementation of these LOS indexes would likely provide enough information to produce a document of non-motorized transportation recommendations.

The transit LOS index is perhaps the least-developed aspect of this multimodal LOS project. During the literature review phase, the project team learned that pre-existing transit LOS concepts and methodologies can be very complex and require data that is usually only available from large transit agencies that engage in performance tracking. Therefore the project team developed the transit LOS index based on what data would be easily available or could be easily collected in the WILMAPCO region. In the process of implementing the transit LOS index in Elkton, however, the researcher realized that bus stop and bus schedule information is not as straightforward as expected. First, there appears to be some discrepancy between the bus stop locations published on the transit service's website and the bus stops that were found in the field visit. Second, the Cecil County transit service has a scheduling system whereby some stops are only serviced if a customer calls ahead of time. The "average headway" and "hours of service" index factors were not designed to account for this type of scheduling, which made the index implementation more difficult. In general, the researcher learned that more time and careful information gathering is required for the successful implementation of the transit LOS index.

5.2 Suggestions for Further Research

The multimodal LOS indexes developed for this project have been implemented in two different pilot projects and have gone through several rounds of revision. Members of the project team believe that these indexes represent valid measurement tools for multimodal LOS in suburban-type areas. However, there is still room for further research and improvement. First, the transit LOS index did not receive as much feedback and revision as the pedestrian and bicycle LOS indexes. Additionally, the transit index did not receive the same amount of real-world validation because of its omission from the Route 2 pilot study and the difficulties encountered in the Elkton study mentioned above. To further refine and validate this transit LOS index, it would be beneficial to carefully apply the index to a sample of roadways in a more transit-heavy area (such as downtown Wilmington) and present the results to the NMTWG or other committees for feedback and suggestions.

The bicycle and pedestrian LOS indexes could also benefit from additional validation activities. As mentioned in the conclusion of Chapter 4, the "extremes" of the LOS indexes should be tested by applying the bicycle and pedestrian indexes to at least one "bad" roadway and one "good" roadway. In other words, the ability of the indexes to assign LOS grades of A and F should be tested. An example of a pedestrian and bicycle *friendly* roadway to test is Delaware Avenue in Newark, due to the presence of continuous sidewalks, bicycle lanes, and good crossing facilities at intersections. This roadway and its intersections could be expected to receive LOS grades of A for the bicycle and pedestrian modes. An example of a pedestrian and bicycle *unfriendly* roadway to test is US 202 in north Wilmington, due to its intermittent sidewalks, lack of bicycle lanes, and intermittent crossing facilities, as well as high vehicle volumes and speeds. Many segments and intersections along this roadway could be expected to receive bicycle and pedestrian LOS grades of F.

Another good test of the validity of the pedestrian and bicycle LOS indexes would be to conduct a direct comparison of these indexes to another LOS measurement methodology. In particular, it would be useful to find a LOS methodology that is less time-consuming to implement than these LOS indexes. The results of the two methodologies could be compared after they are implemented on the exact same sample of road segments and intersections. The Complete Streets LOS software from Dowling Associates (2010) provides an easy-to-use interface for implementing the *NCHRP Report 616* (2008) LOS methodologies. Though the use of this software is not free of charge, it would likely be beneficial to test this methodology against the multimodal LOS indexes, especially since there would be a significant difference in required time and resource investment of large-scale implementation between these two methodologies. It would be particularly interesting to evaluate whether or not the inclusion of additional factors in the multimodal LOS indexes (such as curb ramps and pedestrian crossing signals) present significant differences in LOS results as compared to the Complete Streets LOS software.

Finally, if these multimodal LOS indexes are to be applied to any more roadways for further studies, the implementation process should be streamlined. As detailed above, data for several index factors could be obtained from technologies such as Google Maps rather than a field visit. For index items that do require a field visit, it may be possible to devise a method of collecting the data via windshield surveys rather than walking the length of the segments. This would help minimize the amount of time spent in the field. Additionally, templates in Excel and ArcGIS could be set up that would speed up the data entry and mapping processes. Streamlining the process of multimodal LOS analysis would make this methodology much more practical for project-level implementation.

5.3 Putting Multimodal LOS in Perspective

The focus of this paper has been on multimodal LOS, a set of transportation facility performance measurement tools that informs the transportation planning process. Oftentimes, the ultimate goal of multimodal LOS analyses is to encourage the transfer of a portion of automobile trips to bicycle, pedestrian, or transit trips. Wider use of alternative transportation is desirable for several reasons, including environmental protection, climate change mitigation, public health concerns (including air quality and physical activity), social equity, and infrastructure cost control to name a few. The obvious assumption behind multimodal LOS is that there are certain physical and regulatory characteristics of a roadway environment that influence (and often determine) user mode choice. While aspects of this assumption are certainly true, there is no doubt that factors outside of the built roadway environment affect the actions of travelers.

Unfortunately, measuring multimodal LOS and using these performance measures in planning and engineering practices cannot in itself solve the mobility problems facing communities across the United States. One of the largest contributors to mobility problems today—and throughout the history of the automobile—is the disconnect between land use planning (origins and destinations) and transportation planning (how we get between these origins and destinations). The entire premise of level of service analysis is narrowly focused on transportation infrastructure and cannot account for land use. The historic and current reliance on LOS as a transportation planning tool, even with multimodal considerations, still lacks an ability to fully address mobility problems because of its ignorance of the systemicity of transportation and land use. As Reid Ewing (1993) explains:

> The combined land-use/transportation system is just that—a system—but it is seldom planned or managed as such. Instead, roads are viewed in isolation, and system performance is measured by levels-of-service on individual roadways. Operating speed becomes the essential element in transportation planning. (p. 10)

Even though transportation planners and engineers are moving away from vehicle operating speed as the primary measure of transportation system performance, the overall goal of transportation planning is still often seen as moving people and goods in an efficient and economical manner. This "efficiency" is sometimes pursued with little regard for the well-documented fact that transportation infrastructure designed for current and expected travel behaviors only exacerbates mobility problems: wider and faster roadway facilities allow and encourage more dispersed land uses, which in turn necessitate an increased number of wider and faster roads, and so on (Khisty and Ayvalik 2003, p. 54).

In addition to ignoring the land use aspect of transportation systems, multimodal LOS is a decidedly one-dimensional performance measurement tool. The indicators, or factors evaluated in multimodal LOS are largely physical and structural. Evaluations of systems (such as land use/transportation systems that interact with people, the environment, and social constructs), however, call for a broader and more nuanced exploration of a variety of performance indicators. Khisty and Ayvalik (2003) describe a method of system evaluation called "multimodal methodology," or MMM, that can be used to more holistically monitor and evaluate systems and can be specifically applied to transportation systems (p. 66). "Multimodal" in this context refers to multiple aspects (modes) of performance indicators, not transportation modes. Figure 5.1 shows a table of fifteen "multimodal" performance indicators along with sample questions that clarify the indicators' intent. Multimodal LOS analyses clearly address the bottom three indicators but none of the rest. While a transportation performance measurement tool that addresses all of these indicators would be difficult to develop due to its extreme subjectivity, it is worth noting these other aspects of evaluation that are pertinent to transportation systems.

Performance indicator	Clarifying sample question
Credal	Are the right things being done in the short and long term?
Ethical	Are the planning and implementation morally correct and ethical?
Juridical	Are the planning and implementation just and fair?
Aesthetic	Is the plan aesthetically satisfying?
Economic	Are the resources being used optimally?
Social	Are the social needs of the people respected and accounted for?
Informatory	Have all jurisdictions been duly represented and consulted?
Historical	Have lessons from the past (good and bad) been duly considered?
Logical	Are all the results of the models used reliable, logical, and realistic?
Sensitive	Is the system (and subsystems) sufficiently robust to handle changes?
Biotic	Have the concepts of sustainability (for air, water, soil, etc.) been taken care of?
Physical	Has the system taken the best advantage of the topography and soil conditions?
Kinematic	Has the movement of people, vehicles, and goods been designed for safety, comfort, convenience, economy, and sustainability?
Spatial	Have the land-use pattern and distribution of activities been designed for the health, safety, and convenience of the people?
Numerical	Has the quantitative analysis been done using the best methods available and based on the most reliable data collected?

Figure 5.1 “Multimodal Methodology” performance indicators and sample questions. Source: Khisy, C. and Ayvalik, C. (2003). Automobile dominance and the tragedy of the land use/transportation system: Some critical issues. *Systemic Practice and Action Research,* Vol. 16, No. 1, February 2003, p. 69.

The most striking shortcoming of multimodal LOS analyses is that the concept of multimodal LOS, as manifested in the majority of the literature, may be seen as reinforcing the culture of automobile dominance. Multimodal LOS essentially looks at the current roadway system—which overwhelmingly favors the automobile—and evaluates to what extent the roadway does or could possibly "accommodate" non-automobile modes. This framing of the issue accepts the status quo that the automobile is the dominant mode of travel whose mobility needs take precedence over all other modes. It is no surprise that multimodal LOS does little to meaningfully challenge the auto-centrality of our roadway network. Our transportation system—and indeed our whole way of life—is largely dictated by the needs of automobiles and their drivers. As Peter Calthorpe explains:

> The car is now the defining technology of our built environment. It sets the form of our cities and towns. It dictates the scale of streets, the relationship between buildings, the need for vast parking areas, and the speed at which we experience our environment. Somewhere between convenience and congestion, the automobile dominates what were once diverse streets shared by pedestrians, cyclists, trolleys, and the community at large. (1991, p. 45)

While this assessment is certainly dated, it is still true that throughout history, the U.S. transportation system has transformed from a network of multimodal—often inefficient—streets to a network of functionally-classified, high-speed roadways that "efficiently" move people and goods within and between cities. Multimodal LOS does not—and perhaps cannot—reform the fundamental assumptions of the existing U.S. transportation system. However, many of these fundamental assumptions are changing, and movements such as Complete Streets and New Urbanism are working to alter transportation and land use practice so that the automobile is not king.

So what is the purpose of multimodal LOS analysis and how can it contribute to a more healthy environment, population, and society? It would be easy to say that only a dramatic re-imagining of our transportation system and our relationship to the automobile could possibly achieve a functionally multimodal and equal-access transportation system. It is not so easy to implement such a re-imagining. The use of multimodal LOS analysis in transportation engineering and planning is simply a first step in the right direction. Beyond multimodal LOS analysis, the challenge will be to develop a transportation and land use system that provides for the safe and efficient movement of all people using all modes while working within budgetary, physical, and political constraints. Multimodal LOS, however imperfectly, takes an existing institutionalized practice (LOS analysis) and tilts it away from automobile-centricity by broadening its scope. While more radical critiques and transformations of the U.S. transportation system should certainly still be pursued, multimodal LOS analysis is a feasible and digestible first step in effecting change.

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APPENDIX A:

MULTIMODAL LOS INDEXES—FIRST DRAFT

Pedestrian Segment Level of Service Index

Presence of Sidewalk	6 Points Max
Continuous on both sides	6
Continuous on one side	4
Non-existent or not continuous	0

Width of Sidewalk	3 Points Max
> 5 ft	3
5 ft and barrier free	2
< 5 ft or containing significant barriers	0

Mid-Block Crossing Opportunities	2 Points Max
Crosswalk spacing < 1,000 ft with crossing light	2
Crosswalk spacing < 1,000 ft	1
Crosswalk spacing > 1,000 ft	0

Potential for Vehicle Conflicts	2 Points Max
< 11 driveways and sidestreets/mile	2
11-22 driveways and sidestreets/mile	1
> 22 driveways and sidestreets/mile	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Pedestrian Crash Rate*	2 Points Max
None per mile	2
> 0 to county average	1
> county average	0

Percentage Heavy Vehicles	2 Points Max
0-3%	2
> 3-6%	1
> 6%	0

Sidewalk Pavement Condition	2 Points Max
Excellent; completely ADA compliant	2
Acceptable; no major cracks or uneven surfaces	1
Poor; not ADA compliant	0

Posted Speed Limit (mph)	1 Point Max
< 35	1
35-45	0.5
> 45	0

Buffer between Sidewalk and Road	1 Point Max
Continuous, greater than 3.3 ft	1
No buffer	0

Mid-Block Medians	1 Point Max
Consistent medians	1
No medians	0

Street Trees	0.5 Points Max
Dominant feature	0.5
Not present or infrequent	0

Benches or Pedestrian-Scale Lighting	0.5 Points Max
Dominant feature	0.5
Not present or infrequent	0

LOS Scoring	
LOS A→	22 to 25
LOS B→	18 to 21
LOS C→	14 to 17
LOS D→	9 to 13
LOS E→	5 to 8
LOS F→	0 to 4

Pedestrian Intersection Level of Service Index

Crossing Width (lanes)	2 Points Max
2 or less	2
3 to 5	1
6 or more	0

Crosswalk	2 Points Max
Crosswalk w/ good visibility	2
Crosswalk present	1
No crosswalk	0

Pedestrian Crossing Signal	2 Points Max
Signal w/ countdown	2
Crossing signal	1
No crossing signal	0

Curb at Crossing Point	3 Points Max
ADA curb cut, bulbout, and ADA truncated domes	3
Curb cut and bulbout	2
Proper curb cut provided	1
No curb cut	0

Median/Pedestrian Refuge	2 Points Max
Median extends into crosswalk	2
Median present	1
No median	0

Posted Speed Limit (mph)	2 Points Max
< 35	2
35-45	1
> 45	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Pedestrian Crashes	2 Points Max
None	2
1-2	1
3 or more	0

RTOR Allowed	0.5 Points Max
Not allowed	0.5
Allowed	0

RT Channelization Islands	0.5 Points Max
Present	0.5
Not present	0

LOS Scoring	
LOS A→	16 to 18
LOS B→	13 to 15
LOS C→	9 to 12
LOS D→	6 to 8
LOS E→	3 to 5
LOS F→	0 to 2

* RTOR = Right Turn on Red

* RT = Right Turn

Bicycle Segment Level of Service Index

Width of Outside Lane (ft)	5 Points Max
> 14	5
> 12-14	3
12 or less	0

Striped/Marked Bicycle Lane	2 Points Max
Marked lane	2
No marked lane	0

Barriers to Thru-Movement	2 Points Max
Free of barriers and drainage grates installed properly	2
Largely free of barriers	1
Significant barriers present	0

Pavement Condition/Maintenance	2 Points Max
Excellent pavement condition	2
Very few pavement condition issues	1
Major pavement cracks, potholes, standing water	0

Bicycle Crash Rate*	2 Points Max
None per mile	2
> 0 to county average	1
> county average	0

LOS Scoring	
LOS A→	20 to 23
LOS B→	16 to 19
LOS C→	12 to 15
LOS D→	8 to 11
LOS E→	4 to 7
LOS F→	0 to 3

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Percentage Heavy Vehicles	2 Points Max
0-3%	2
> 3-6%	1
> 6%	0

Posted Speed Limit (mph)	2 Points Max
< 35	2
35-45	1
> 45	0

Potential for Vehicle Conflicts	2 Points Max
< 11 driveways and sidestreets/mile	2
11-22 driveways and sidestreets/mile	1
> 22 driveways and sidestreets/mile	0

On-Street Parking	1 Point Max
Not present	1
Present	0

Mid-Block Medians	1 Point Max
Consistent medians	1
No medians	0

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Bicycle Intersection Level of Service Index

Width of Outside Thru-Lane (ft)	2 Points Max
> 14	2
> 12-14	1
12 or less	0

Bike Lane	1 Point Max
Continuous through intersection approach	1
Not-continuous	0

Crossing Width (lanes)	2 Points Max
2 or less	2
3 to 5	1
6 or more	0

Bicycle Crashes	1 Point Max
None	1
1-2	0.5
3 or more	0

RTOR Allowed	0.5 Points Max
Not allowed	0.5
Allowed	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

RT Channelization Islands	0.5 Points Max
Present	0.5
Not present	0

Posted Speed Limit (mph)	1 Point Max
< 35	1
35-45	0.5
> 45	0

LOS Scoring	
LOS A→	9 to 10
LOS B→	7 to 8
LOS C→	5 to 6
LOS D→	3 to 4
LOS E→	1 to 2
LOS F→	0

* RTOR = Right Turn on Red

* RT = Right Turn

Transit Segment Level of Service Index

Avg. Headway (in minutes)	4 Points Max
< 15	4
15-30	3
> 30-45	2
> 45-60	1
> 60	0

Transit Stop Amenities	2 Points Max
Bus shelter	+1
Route/schedule info	+0.5
Bench	+0.5
None	0

Hours of Service	4 Points Max
Late evening/night service provided	+1
Early evening service provided	+1
Mid-day service provided	+1
Service at peak hours	+1
Limited or no service	0

Avg. Interval Between Stops	1 Point Max
1/4 to 1/2 mile	1
> 1/2 mile	0

Pedestrian LOS	2 Points Max
A-B	2
C-D	1
E-F	0

LOS Scoring	
LOS A→	11 to 13
LOS B→	8 to 10
LOS C→	6 to 7
LOS D→	4 to 5
LOS E→	2 to 3
LOS F→	0 to 1

APPENDIX B:

MULTIMODAL LOS INDEXES—SECOND DRAFT (NON-MOTORIZED TRANSPORTATION WORKING GROUP REVISIONS)

Pedestrian Segment Level of Service Index

Presence of Sidewalk	6 Points Max
Continuous on both sides	6
Continuous on one side	4
Non-existent or not continuous	0

Width of Sidewalk	3 Points Max
> 5 ft	3
5 ft and barrier free	2
4-5 ft	1
< 4 ft or containing significant barriers	0

Pedestrian Crashes	3 Points Max
None	3
1-2	2
3 or more	0

Potential for Vehicle Conflicts	2 Points Max
< 15 driveways/mile	2
15-30 driveways/mile	1
> 30 driveways/mile	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Posted Speed Limit (mph)	2 Points Max
25 or less	2
> 25-35	1
> 35-45	0.5
> 45	0

Percentage Heavy Vehicles	2 Points Max
0-3%	2
> 3-6%	1
> 6%	0

Sidewalk Pavement Condition	2 Points Max
Excellent; completely ADA compliant	2
Acceptable; no major cracks or uneven surfaces	1
Poor; not ADA compliant	0

Sidewalk Offset/Buffer	1 Point Max
Continuous, greater than 3.3 ft	1
No buffer	0

Mid-Block Medians	1 Point Max
Consistent medians	1
No medians	0

Street Trees	0.5 Points Max
Dominant feature	0.5
Not present or infrequent	0

Benches or Pedestrian-Scale Lighting	0.5 Points Max
Dominant feature	0.5
Not present or infrequent	0

Cross Slope of Driveways	1 Point Max
Driveways all or mostly at sidewalk grade	1
Driveways not consistent with sidewalk grade	0

Walking Appeal	1 Point Max
Pleasant walking environment	1
Unpleasant walking environment	0

Mid-Segment Crossing Opportunities	1 Point Max
Crosswalk spacing < 1,000 ft	1
Crosswalk spacing > 1,000 ft	0

Pedestrian Intersection Level of Service Index

Pedestrian Crossing Signal	3 Points Max
ADA-Accessible signal	3
Signal w/ countdown	2
Crossing signal	1
No crossing signal	0

Curb at Crossing Point	3 Points Max
ADA curb cut, bulbout, and ADA truncated domes	3
Curb cut and bulbout	2
Proper curb cut provided	1
No curb cut	0

Pedestrian Crashes	3 Points Max
None	3
1-2	2
3 or more	0

Crosswalk	2 Points Max
Marked crosswalk w/ good visibility	2
Marked crosswalk present	1
No crosswalk	0

Median/Pedestrian Refuge	2 Points Max
Median extends into crosswalk	2
Median present	1
No median	0

Posted Speed Limit (mph)	2 Points Max
25 or less	2
> 25-35	1
> 35-45	0.5
> 45	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Turning Vehicle Conflicts	2 Points Max
No turning vehicles on pedestrian phase	2
RTOR and/or LT on pedestrian phase allowed*	0

Crossing Width (lanes)	2 Points Max
2 or less	2
3 to 5	1
6 or more	0

* RTOR = Right Turn on Red

LT = Left Turn

Bicycle Segment Level of Service Index

Width of Outside Lane (ft)	5 Points Max
Marked bicycle lane	5
> 14 ft	3
> 12-14	1
12 or less	0

Barriers to Thru-Movement	2 Points Max
Free of barriers; drainage grates installed properly; RT lanes do not interrupt shoulder/bike lane	2
Largely free of barriers	1
Significant barriers present	0

Posted Speed Limit (mph)	3 Points Max
25 or less	3
> 25-35	2
> 35-45	1
> 45	0

Bicycle Crashes	3 Points Max
None	3
1-2	2
3 or more	0

Pavement Condition/Maintenance	2 Points Max
Excellent pavement condition	2
Very few pavement condition issues	1
Major pavement cracks, potholes, standing water	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Percentage Heavy Vehicles	2 Points Max
0-3%	2
> 3-6%	1
> 6%	0

Potential for Vehicle Conflicts	2 Points Max
< 11 driveways/mile	2
11-22 driveways/mile	1
> 22 driveways/mile	0

On-Street Parking	1 Point Max
Not present	1
Present	0

Mid-Block Medians	1 Point Max
Consistent medians	1
No medians	0

Bicycling Appeal	1 Point Max
Pleasant cycling environment	1
Unpleasant cycling environment	0

Bicycle Intersection Level of Service Index

Posted Speed Limit (mph)	3 Points Max
25 or less	3
> 25-35	2
> 35-45	1
> 45	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Bicycle Crashes	3 Points Max
None	3
1-2	2
3 or more	0

Crossing Width (lanes)	2 Points Max
2 or less	2
3 to 5	1
6 or more	0

Width of Outside Thru-Lane (ft)	2 Points Max
> 14	2
> 12-14	1
12 or less	0

RTOR Allowed*	1 Point Max
Not allowed	1
Allowed	0

Bike Lane	2 Points Max
Continuous through intersection approach	2
Not-continuous	0

* RTOR = Right Turn on Red

Transit Segment Level of Service Index

Avg. Headway (in minutes)	4 Points Max
< 15	4
15-30	3
> 30-45	2
> 45-60	1
> 60	0

Hours of Service	4 Points Max
Late evening/night service provided	+1
Early evening service provided	+1
Mid-day service provided	+1
Service at peak hours	+1
Limited or no service	0

Pedestrian LOS	2 Points Max
A-B	2
C-D	1
E-F	0

Transit Stop Amenities	2 Points Max
Bus shelter	+1
Route/schedule info	+0.5
Bench	+0.5
None	0

Avg. Interval Between Stops	1 Point Max
1/4 to 1/2 mile	1
> 1/2 mile	0

Level of Service Scoring Key

LOS Scoring	Pedestrian Segment
LOS A→	25 to 28
LOS B→	20 to 24
LOS C→	15 to 19
LOS D→	10 to 14
LOS E→	5 to 9
LOS F→	0 to 4

LOS Scoring	Pedestrian Intersection
LOS A→	18 to 21
LOS B→	14 to 17
LOS C→	10 to 13
LOS D→	7 to 9
LOS E→	4 to 6
LOS F→	0 to 3

LOS Scoring	Bicycle Segment
LOS A→	21 to 24
LOS B→	17 to 20
LOS C→	12 to 16
LOS D→	8 to 11
LOS E→	4 to 7
LOS F→	0 to 3

LOS Scoring	Bicycle Intersection
LOS A→	14 to 15
LOS B→	11 to 13
LOS C→	8 to 10
LOS D→	5 to 7
LOS E→	2 to 4
LOS F→	0 to 1

LOS Scoring	Transit Segment
LOS A→	11 to 13
LOS B→	8 to 10
LOS C→	6 to 7
LOS D→	4 to 5
LOS E→	2 to 3
LOS F→	0 to 1

APPENDIX C:

MULTIMODAL LOS INDEXES—FINAL DRAFT

Pedestrian Segment Level of Service Index

Presence of Sidewalk	6 Points Max
Continuous	6
Continuous > 50% of segment	3
Continuous <50% of segment	1
Non-existent	0

Width of Sidewalk	3 Points Max
> 5 ft	3
5 ft and barrier free	2
4-5 ft	1
< 4 ft or containing significant barriers	0

Pedestrian Crashes	0 Points Max
None	0
1-2	-1
3 or more	-2

Potential for Vehicle Conflicts	2 Points Max
< 15 driveways/mile	2
15-30 driveways/mile	1
> 30 driveways/mile	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Posted Speed Limit (mph)	2 Points Max
25 or less	2
> 25-35	1
> 35-45	0.5
> 45	0

Percentage Heavy Vehicles	2 Points Max
0-3%	2
> 3-6%	1
> 6%	0

Sidewalk Pavement Condition	2 Points Max
Excellent; completely ADA compliant	2
Acceptable; no major cracks or uneven surfaces	1
Poor; not ADA compliant	0

Sidewalk Offset/Buffer	1 Point Max
Continuous, greater than 3 ft	1
No buffer	0

Mid-Block Medians	1 Point Max
Consistent medians	1
No medians	0

Street Trees	0.5 Points Max
Dominant feature	0.5
Not present or infrequent	0

Benches or Pedestrian-Scale Lighting	0.5 Points Max
Dominant feature	0.5
Not present or infrequent	0

Cross Slope of Driveways	1 Point Max
Driveways all or mostly at sidewalk grade	1
Driveways not consistent with sidewalk grade	0

Walking Appeal	1 Point Max
Pleasant walking environment	1
Unpleasant walking environment	0

Mid-Segment Crossing Opportunities	1 Point Max
Crosswalk spacing < 1,000 ft	1
Crosswalk spacing > 1,000 ft	0

Pedestrian Intersection Level of Service Index

Pedestrian Crossing Signal	3 Points Max
ADA-Accessible signal	3
Signal w/ countdown	2
Crossing signal	1
No crossing signal	0

Curb at Crossing Point	3 Points Max
ADA curb cut, bulbout, and ADA truncated domes	+1
Curb cut and bulbout	+1
Proper curb cut provided	+1
No curb cut	0

Pedestrian Crashes	0 Points Max
None	0
1-2	-1
3 or more	-2

Crosswalk	2 Points Max
Marked crosswalk w/ good visibility	2
Marked crosswalk present	1
No crosswalk	0

Median/Pedestrian Refuge	2 Points Max
Median extends into crosswalk	2
Median present	1
No median	0

Posted Speed Limit (mph)	2 Points Max
25 or less	2
> 25-35	1
> 35-45	0.5
> 45	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Turning Vehicle Conflicts	2 Points Max
Exclusive pedestrian phase	2
No RTOR allowed*	1
RTOR allowed*	0

Crossing Width (lanes)	2 Points Max
2 or less	2
3 to 5	1
6 or more	0

* RTOR = Right Turn on Red

Bicycle Segment Level of Service Index

Width of Outside Lane (ft)	5 Points Max
Marked bicycle lane	5
Sharrow markings	4
> 14 ft	3
> 12-14	1
12 or less	0

Barriers to Thru-Movement	2 Points Max
Free of barriers; drainage grates installed properly; RT lanes do not interrupt shoulder/bike lane	2
Largely free of barriers	1
Significant barriers present	0

Posted Speed Limit (mph)	3 Points Max
25 or less	3
> 25-35	2
> 35-45	1
> 45	0

Bicycle Crashes	0 Points Max
None	0
1-2	-1
3 or more	-2

Pavement Condition/Maintenance	2 Points Max
Excellent pavement condition	2
Very few pavement condition issues	1
Major pavement cracks, potholes, standing water	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Percentage Heavy Vehicles	2 Points Max
0-3%	2
> 3-6%	1
> 6%	0

Potential for Vehicle Conflicts	2 Points Max
< 15 driveways/mile	2
15-30 driveways/mile	1
> 30 driveways/mile	0

Mid-Block Medians	1 Point Max
Consistent medians	1
No medians	0

Bicycling Appeal	1 Point Max
Pleasant cycling environment	1
Unpleasant cycling environment	0

Bicycle Intersection Level of Service Index

Posted Speed Limit (mph)	3 Points Max
25 or less	3
> 25-35	2
> 35-45	1
> 45	0

Bicycle Crashes	0 Points Max
None	0
1-2	-1
3 or more	-2

Width of Outside Thru-Lane (ft)	2 Points Max
> 14	2
> 12-14	1
12 or less	0

Bike Lane	2 Points Max
Continuous through intersection approach	2
Not-continuous	0

Traffic Volume (AADT)	2 Points Max
< 10,000	2
10,000-20,000	1
> 20,000-30,000	0.5
> 30,000	0

Crossing Width (lanes)	2 Points Max
2 or less	2
3 to 5	1
6 or more	0

RTOR Allowed*	1 Point Max
Not allowed	1
Allowed	0

* RTOR = Right Turn on Red

Transit Segment Level of Service Index

Avg. Headway (in minutes)	4 Points Max
< 15	4
15-30	3
> 30-45	2
> 45-60	1
> 60	0

Hours of Service	4 Points Max
Late evening/night service provided	+1
Early evening service provided	+1
Mid-day service provided	+1
Service at peak hours	+1
Limited or no service	0

Pedestrian LOS	2 Points Max
A-B	2
C-D	1
E-F	0

Transit Stop Amenities	2 Points Max
Bus shelter	+1
Route/schedule info	+0.5
Bench	+0.5
None	0

Avg. Interval Between Stops	1 Point Max
1/4 to 1/2 mile	1
> 1/2 mile	0

LOS Scoring	Pedestrian Segment
LOS A→	22 to 25
LOS B→	18 to 21
LOS C→	14 to 17
LOS D→	10 to 13
LOS E→	6 to 9
LOS F→	5 or less

LOS Scoring	Pedestrian Intersection
LOS A→	16 to 18
LOS B→	13 to 15
LOS C→	9 to 12
LOS D→	6 to 8
LOS E→	3 to 5
LOS F→	2 or less

LOS Scoring	Bicycle Segment
LOS A→	18 to 20
LOS B→	15 to 17
LOS C→	11 to 14
LOS D→	7 to 10
LOS E→	3 to 6
LOS F→	2 or less

LOS Scoring	Bicycle Intersection
LOS A→	11 to 12
LOS B→	9 to 10
LOS C→	6 to 8
LOS D→	4 to 5
LOS E→	2 to 3
LOS F→	1 or less

LOS Scoring	Transit Segment
LOS A→	12 to 13
LOS B→	10 to 11
LOS C→	7 to 9
LOS D→	4 to 6
LOS E→	2 to 3
LOS F→	0 to 1

APPENDIX D:

INDEX FACTOR DATA REQUIREMENTS AND OPERATIONAL DEFINITIONS

D.1 Remotely Gathered Data

Pedestrian and Bicycle crashes [Segment and Intersection]: Pedestrian and bicycle crash data came from a GIS point file of pedestrian and bicycle crashes created by DelDOT. The data is from the years 2006-2008. For segment indexes, any crash occurring on the segment of interest was counted towards that index factor. For intersection indexes, any crashes occurring within a 50-foot radius of the center of the intersection were counted. The GIS buffer tool was used to create the 50-foot counting radius.

Potential for Vehicle Conflicts [Segment]: Aerial photos were used to count the number of potential vehicle conflicts. Driveways (commercial) and side streets were counted for each side of the roadway separately. High-quality aerial photos were provided by WILMAPCO. The aerial photos used in the Route 2 study were from 2003, and the photos used in the Elkton, MD study were from 2008.

Traffic Volume (AADT) [Segment and Intersection]: For the Route 2 pilot study, AADT information was obtained from the DelDOT GIS centerline files. Where the AADT numbers changed from segment to segment along Route 2, new values were entered into the index.

For the ten roadways of interest in Elkton, MD (including the cross-streets at intersections) a combination of data sources was used. Centerline files were obtained from the Maryland State Highway Administration. Most of the AADT information contained in the centerline files was from 1998, which the project team considered too old to be reliable. An additional map, “Cecil County Truck Volume Map 2007-2009,” was obtained from the Maryland DOT website. This map provided AADT information for seven out of the ten roadways for which data was needed. The map did not, however, include AADT counts for three of the small roadways included in the study. For one of these roadways, Howard Street, a 2009 AADT count was available from WILMAPCO's 2010 "Elkton Signage Study." For the other two roadways, Whitehall Rd. and Elkton Blvd., a "2009" AADT value was computed using a percent change methodology based on the surrounding roadways. This methodology was recommended by staff at WILMAPCO, and in both cases the change in AADT resulting from this calculation was too small to have any effect on the index factor score. An excel file showing this AADT computation is shown in Figure D-1.

For the pedestrian intersection LOS index, AADT data are used from the road being crossed by the pedestrian. For the bicycle intersection LOS index, AADT data are used from the road that the bicyclist is riding on. This same principle is applied to the "posted speed limit" factor used in the pedestrian and bicycle intersection LOS indexes. Figure D-2 illustrates this concept.

Roadway	1998 AADT	2009 AADT	% Change	Imputed 2009 AADT	Notes			
MD545	4525	5340	18.01%					
MD279	9250	10192	10.18%					
MD213(N)	18225	18520	1.62%					
MD213(S)	18525	18980	2.46%					
Elkton Blvd	4525			5339.5	used 18% based on surrounding roads			
Howard		6898*			Elkton truck count study			
Delancy	5225	11020	110.91%					
MD281	5225	6680	27.85%					
US40(W)	31925	30713	-3.80%					
US40(C)	28075	30803	9.72%					
US40(E)	23575	28213	19.67%					
MD7(W)	7300	3662	-49.84%					
MD7(E)	7025	7422	5.65%					
Whitehall	3675			4005.75	used 9% based on surrounding roads			
Letters in parentheses indicate the portion of road (North, South, etc.)								
that was used where there were multiple AADT counts								

Figure D-1: Elkton, MD AADT Computation Examples

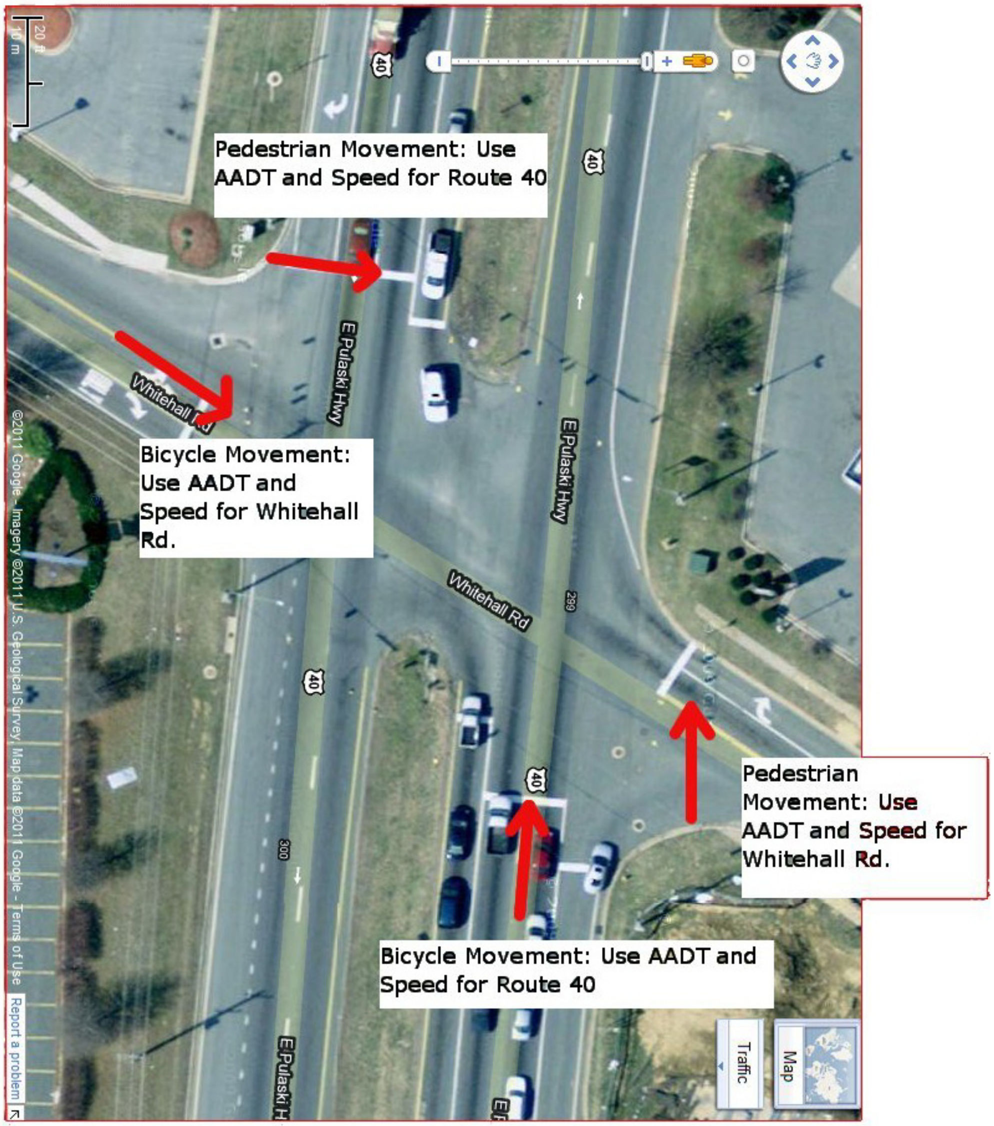

Figure D-2 Difference between traffic data sources for bicycles and pedestrians at intersections. Image source: Google Maps

Percentage of Heavy Vehicles [Segment]: For the Route 2 pilot study, percentage of heavy vehicles was available from the DelDOT centerline files. Because the DelDOT-defined road segments differed from our defined road segments, the percent heavy vehicles value from a DelDOT segment sometimes changed in the middle of our defined segment. When the percentage values changed along Route 2, an average of the two percentage values surrounding the segment of interest was computed. For the Elkton, MD study, heavy vehicle truck counts were obtained from the "Cecil County Truck Volume Map 2007-2009" from the Maryland DOT website. In this case, the truck count closest to the segment of interest was used as the value for the index. Heavy vehicle volume counts were not available for a number of the roads in the Elkton study. For these roadways, a value of 4% was used as a "medium" level of heavy truck traffic in the absence of reliable data, in accordance with heavy vehicle percentages for similar roadway types in the Elkton area.

Mid-Block Medians [Segment]: Aerial photos imported into the GIS map were used to identify segments with consistent mid-block medians. A median of any size, as long as it provides center turn lane movement control, receives points for this factor. The aerial photos used in the Route 2 study were from 2003, and the photos used in the Elkton study were from 2008.

Mid-Segment Crossing Opportunities [Segment]: Aerial photos imported into the GIS map were primarily used to identify and count the number of mid-segment crossing opportunities (where a mid-segment crosswalk is present). This information was supplemented by a count of four-way stop locations during the Elkton study. The number of crossing opportunities and the length of the segment in feet is used to calculate the frequency of crossing opportunities for each segment (number of crossing opportunities per 1,000 feet). The aerial photos used in the Route 2 study were from 2003, and the photos used in the Elkton study were from 2008.

Median/Pedestrian Refuge in Crosswalk [Pedestrian Intersection]: Aerial photos imported into the GIS map were used to note the presence of medians at each intersection. These photos were also used to determine if the median extended into the crosswalk and if the median was of sufficient size for a pedestrian to stand in it. The size and condition of the median was also evaluated in the field to supplement the photo. The aerial photos used in the Route 2 study were from 2003, and the photos used in the Elkton study were from 2008.

Intersection Crossing Width [Pedestrian and Bicycle Intersection]: Aerial photos imported into the GIS map were used to count the number of lanes at each intersection. The total number of lanes on each leg of the intersection, including right-turn slip lanes, are used to calculate the factor score. The aerial photos used in the Route 2 study were from 2003, and the photos used in the Elkton study were from 2008.

Width of Outside Lane (bike lane/sharrow markings evaluated in field) [Bicycle Segment]: Aerial photos imported into the GIS map as well as the ArcMap distance measuring tool are used to measure the width of the outside lane on each segment. The measurement is taken from the painted inner line of the outside lane to the edge of the pavement or gutter pan. GIS aerial photos or Google Earth can be used to measure this distance (see figure D-3). The aerial photos used in the Route 2 study were from 2003, and the photos used in the Elkton study were from 2008. If the width of the outside lane varies throughout the segment, several measurements are taken and the most dominant value is used. Infrequent lane narrowing is accounted for in the "barriers to through-movement" factor.

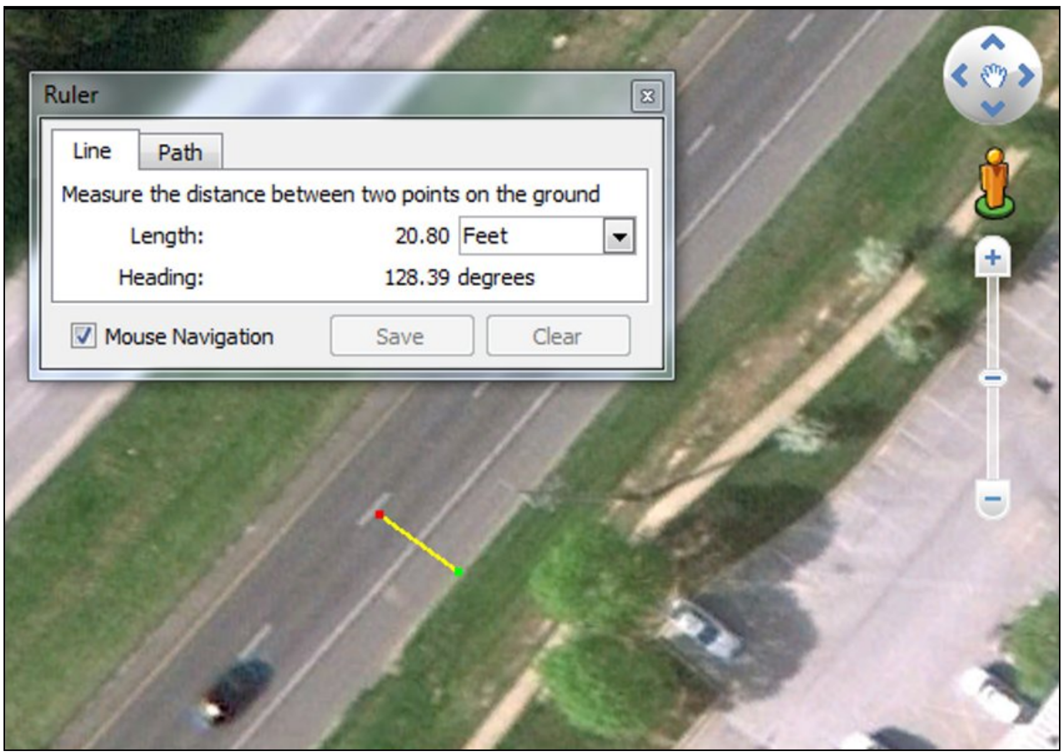

Figure D-3: Measuring "width of outside lane" with Google Earth. Image source: Google Earth

Width of Outside Thru-Lane [Bicycle Intersection]: Aerial photos and the ArcMap distance measuring tool are also used to measure this factor. The measurement is taken with essentially the same methodology as used for measuring the width of the outside lane along the segment. Google Earth can also be used to measure this factor (see Figure D-4). The aerial photos used in the Route 2 study were from 2003, and the photos used in the Elkton study were from 2008.

Figure D-4 Measuring "width of outside through-lane" with Google Earth. Image source: Google Earth

Transit Route and Schedule Information [Transit Segment]: Transit route and schedule information for Elkton, MD was obtained from the website for Cecil County's "The Bus" service. The average time between stops on the published bus schedules is used to calculate average headway. Hours of service information is also obtained from published bus schedules.

Interval Between Transit Stops [Transit Segment]: A GIS file of Cecil County bus routes and bus stops was provided by WILMAPCO. The GIS files were developed by WILMPACO based on a 2009 field survey and information from the "Senior Service & Community Transit of Cecil County." Though this analysis was not necessary for the sample of roadways in Elkton, the ArcMap distance measuring tool can be used to measure the distance between transit stop locations.

D.2 Data Gathered in the Field (Site Visit)

Note: Field data was collected on Route 2 in Newark on March 21st, 2010. Field data was collected in Elkton, MD on September 3rd and 10th, 2010.

Presence of Sidewalk [Pedestrian Segment]: This factor is evaluated by walking the entire length of each segment and taking note of the presence and continuity of the sidewalk facility. If there are gaps in the facility, the researcher will make a judgment regarding what percentage of the segment length is covered by continuous sidewalk facilities.

Width of Sidewalk [Pedestrian Segment]: This factor is evaluated by measuring the width of the sidewalk facility at regular intervals while walking the length of the segment. The measurement is taken from the edge of the curb/buffer area to the edge of the grass. While this was not a common experience during the data collection, if the width of the sidewalk facility varies along the segment, an average width is computed. Barriers to pedestrian through-movement were also evaluated as part of this factor and included in width evaluations (see Figure D-5). These include intrusions into the sidewalk (such as utility poles) as well as the presence of ADA-accessible curb ramps at side street intersections. The assessment of this factor's score is based on a combination of sidewalk width and barriers within the sidewalk.

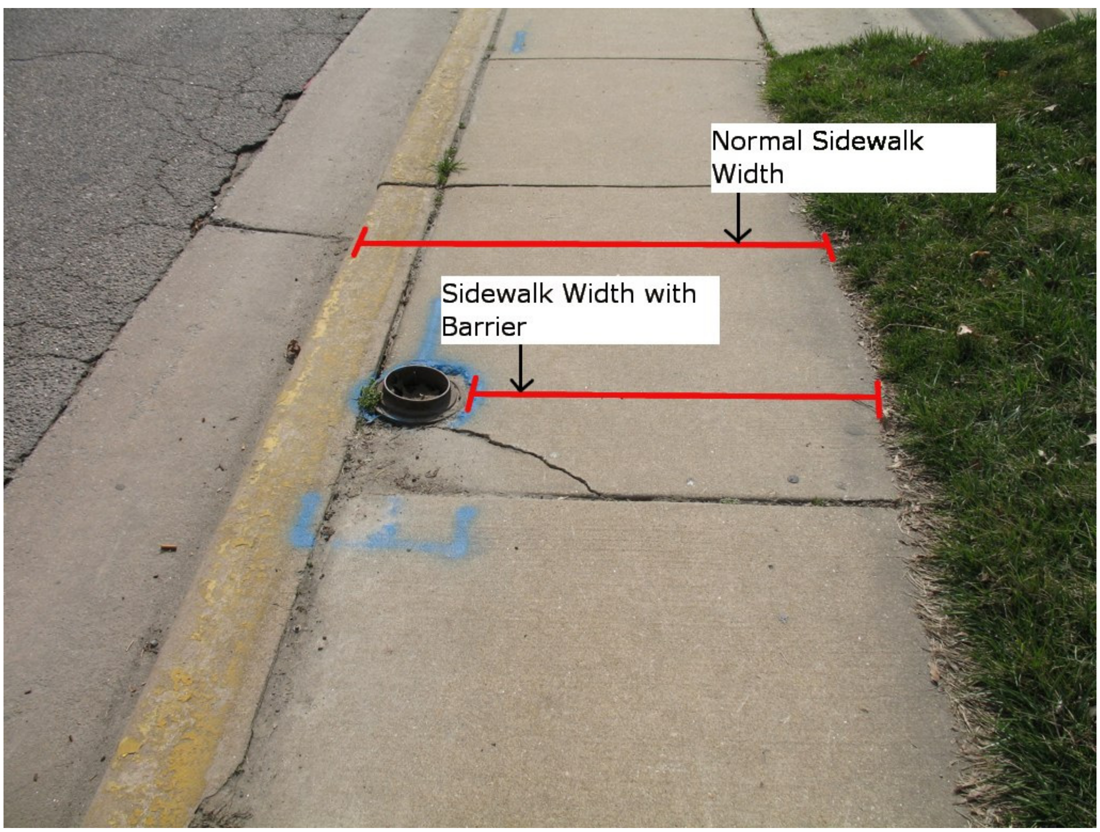

Figure D-5   Sidewalk width evaluation example.

Sidewalk Offset/Buffer [Pedestrian Segment]: The width of the sidewalk offset/buffer area is measured during the field data collection process. The facility only receives points for this factor if the buffer is continuous wherever a sidewalk facility is present.

Posted Speed Limit [Pedestrian and Bicycle Segment and Intersection]: The posted speed limit information is gathered by looking at the speed limit signs during the field data collection process. In some cases (especially for cross-streets at intersections) Google Street View can be used to identify posted speed limits.

Sidewalk Pavement Condition [Pedestrian Segment]: The general condition of the sidewalk facility is observed during the field visit process. Pavement issues such as major cracks, holes, protruding items, and crumbling concrete are noted and photographed along each segment. The researcher then makes a qualitative assessment of the overall condition of the segment's sidewalk pavement.

Street Trees, Benches, and Pedestrian Lighting [Pedestrian Segment]: The presence of street trees, benches, and pedestrian lighting is noted during the field visit. These features must be dominant and consistent along the entire length of the segment in order to receive points.

Cross-Slope of Driveways [Pedestrian Segment]: The cross-slope of driveways intersecting the sidewalk facility is visually evaluated during the field visit process. If the slope of the sidewalk caused by a driveway cut-through seems drastic (i.e. it would pose difficulty for a wheelchair user), that area is noted and photographed. If the majority of cross-slopes at driveway intersections are mild slopes mostly at sidewalk grade, then the segment would receive points for this factor.

Walking Appeal [Pedestrian Segment]: The walking appeal of the area surrounding a segment is subjectively assessed by the researcher in the field. Factors contributing to walking appeal include the presence of interesting/useful destinations, the amount and behavior of traffic on the road, the presence of a safe walking facility, and the visual appeal of the surroundings.

Pedestrian Crossing Signal [Pedestrian Intersection]: If a pedestrian crossing signal is present, this factor is evaluated by activating the signal and crossing all sides of the intersection. The condition of the crossing signal infrastructure is evaluated by looking at the push button. Once the crossing signal is activated, the researcher can determine whether or not the signal provides a countdown. The activity of crossing each side of the intersection also contributes to evaluating turning vehicle conflicts.

Curb at Crossing Point [Pedestrian Intersection]: If a sidewalk at the intersection approach is present, the curb ramp area is evaluated for each side of the intersection separately. The presence of an ADA accessible curb ramp, a bulb-out (curb extension), and installation of truncated domes is noted for each leg of the intersection separately.

Crosswalk Presence [Pedestrian Intersection]: The presence and visibility of painted crosswalks is evaluated while crossing each leg of the intersection.

Turning Vehicle Conflicts [Pedestrian and Bicycle Intersection]: The amount of turning vehicle conflicts at an intersection is evaluated in two ways. First, the approach to each side of the intersection is inspected for the presence of a "No Right Turn on Red" sign. Second, if a pedestrian signal is present, the researcher activates the pedestrian signal and observes its effects on the traffic signals in order to evaluate if the intersection is equipped with an exclusive pedestrian signal phase.

Bike Lane/Sharrow Markings [Bicycle Segment]: The presence and continuity of marked bike lanes or sharrow markings along the segment is evaluated by the researcher in the field.

Barriers to Bicycle Thru-Movement [Bicycle Segment]: While walking along the road segment, the researcher takes note of the following: choke points created by lane narrowing, continuity of shoulder/bike lane facilities, correct perpendicular installation of drainage grates, and right-turn lane interruptions. The frequency of such bicycle facility barriers is noted along the segment and a judgment of the overall bicycle facility is made for scoring the category.

Pavement Condition [Bicycle Segment]: While walking along the road segment, the researcher notes the condition of the pavement in the shoulder, bike lane, or outside portion of the outside traffic lane. Other pavement issues such as standing water or physical obstacles are noted as well. To score the factor, the researcher makes a judgment about the overall pavement condition of the segment.

Bicycling Appeal [Bicycle Segment]: The bicycling appeal of the area surrounding a segment is subjectively assessed by the researcher in the field. Factors contributing to bicycling appeal include the presence of interesting/useful destinations, the amount and behavior of traffic on the road, the presence of a safe bicycling facility, and the visual appeal of the surroundings.

Bike Lane [Bicycle Intersection]: The presence of a continuous bike lane on the intersection approach is noted by the researcher in the field.

Transit Stop Amenities [Transit Segment]: Amenities provided at a transit stop are noted during the field visit. The presence of a bench, shelter, or route and schedule information is noted and scored accordingly.