

MODELING THE ROADSIDE WALKING ENVIRONMENT: A PEDESTRIAN LEVEL OF SERVICE

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ABSTRACT

A method is needed to objectively quantify pedestrians' perception of safety and comfort in the roadside environment. This quantification, or mathematical relationship, would provide a measure of how well *roadways* accommodate pedestrian travel. Essentially it would provide a measure of pedestrian level of service within a roadway environment. Such a measure of walking conditions would greatly aid in roadway cross-sectional design and also help evaluate and prioritize the needs of existing roadways for sidewalk retrofit construction. Furthermore, the measure can be used to evaluate traffic calming strategies and streetscape designs for their effectiveness in improving the pedestrian environment. Such a measure would enable pedestrian facility programming to be merged into the mainstream of transportation planning, design and construction.

To meet the need for such a method, as well as to fulfill a state mandate to establish levels of service standards for *all* transportation modes, the Florida Department of Transportation sponsored the development of the *Pedestrian Level of Service (LOS) Model* as described within this paper. 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. It is similar in approach to the methods used to assess the automobile operators' level of service established in the *Highway Capacity Manual*.

Key Words:

Pedestrian Level of Service, Walking Conditions, Pedestrian Safety, Performance Measure, Sidewalks

INTRODUCTION

In recent years there have been initiatives in metropolitan areas throughout the United States to create more livable communities where walking and bicycling are encouraged and accepted as legitimate forms of transportation. Characteristic of these efforts is the reintroduction of bicycle lanes and sidewalks to the streetscapes, complete with street furniture, landscaping, pedestrian-scaled lighting, and other features making the public right-of-way more inviting for people to travel by bicycle or on foot. The transportation planning and engineering community has recently been attempting to provide analysis and design methods to help create more “livable” streets and roadway environments.

Historically, compared to the level of research that has been done for motorized transportation, there has been relatively little study and analysis of the factors that affect the quality of the walking environment. Evaluating the performance of a roadway section for the walking mode is far more complex in comparison to that of the motor vehicle mode. Whereas operators of motor vehicles are largely insulated in their travel environment and hence are influenced by relatively few factors, the pedestrian is relatively unprotected and is subject to a host of environmental conditions.

In general, planners and engineers have not yet come to consensus on which features of a roadway environment have statistically reliable significance to pedestrians. There have been several recent initiatives by planners to develop “walkability audits”; however, these measures generally include the myriad of features of the entire roadway corridor environment (including conditions at intersections) and they have not yet been statistically tested or widely applied. There is general consensus that pedestrians'

sense of safety / comfort within a roadway corridor is based on a complex assortment of factors including:

- personal safety (i.e., the threat of crashes)
- personal security (i.e., the threat of assault)
- architectural interest
- pathway or sidewalk shade
- pedestrian-scale lighting and amenities
- presence of other pedestrians
- conditions at intersections, and etc.

Complexity of the issue, however, should not deter attempts to model pedestrians' response to the roadway environment, even if it is for one aspect or component of a roadway corridor. Elected representatives, public officials, transportation planners and engineers need the capability to determine a roadway's performance with regard to accommodating pedestrian travel. Roadway designers need solid guidance on how to better design pedestrian environments: how far sidewalks should be placed from moving traffic; when, and what type of buffering or protective barriers are needed; how wide the sidewalk should be; and etc.

The purpose of this study, therefore, was to focus on, and identify those factors within the right-of-way that *significantly influence* the pedestrian's feeling of safety and/or comfort. The collection of these factors into a mathematical expression, tested for statistical reliability, provides a measure of the roadway segment's level of service to pedestrians. This measure evaluates the conditions along roadway segments *between* intersections. A key application of this measure is to help planners and roadway

engineers make informed decisions when designing or choosing the appropriate cross section for any given roadway – a cross section that meets pedestrians' basic need to feel safe and comfortable while walking. As such, the measure presented in this paper is one piece of the puzzle, albeit an important one – many other factors also influence a pedestrian's (enjoyment of the) walking experience. These factors should be studied further to improve the body of knowledge on this subject.

The researchers of this study acknowledge that intersection conditions also have a significant bearing on the pedestrians' total roadway corridor experience, and must also be studied. Further, they believe that a measure(s) must be developed to be combined with this roadway segment performance measure. In fact the research sponsor, the Florida Department of Transportation, is using this research team to develop intersection performance measure(s) as phase II of this Study. The Federal Highway Administration is beginning a similar study initiative.

MEASURES OF THE PEDESTRIAN ENVIRONMENT

Dan Burden, a leading national advocate for more walkable communities and transportation systems, articulates for many that the pedestrian in the roadside environment is subjected to a multitude of factors significantly affecting his/her feeling of safety, comfort, and convenience. Accordingly, we may classify these factors under three general performance measures describing the roadside pedestrian environment; 1) sidewalk capacity, 2) quality of the walking environment, and 3) the pedestrian's perception of safety (or comfort) with respect to motor vehicle traffic. These three are briefly outlined below.

The first performance measure, *sidewalk capacity*, was developed in the early 1970's by Fruin (1). His method, as formalized in the *Highway Capacity Manual* (2), is the only established method of quantifying sidewalk capacity. However, this performance measure is limited in its applicability: it only evaluates conditions for an existing (or a planned) sidewalk and then, only from the perspective of "walking space" or effective sidewalk width available to the pedestrian. Additionally, it cannot be used to evaluate and prioritize roadways for sidewalk retrofit construction, a prevalent need currently in the United States. This is an important limitation. We estimate that typically less than 20% of the collector and arterial network of U.S. metropolitan areas have sidewalks. Furthermore, it is estimated that less than approximately 3% of roadways have pedestrian activity levels that can be effectively measured by Fruin's capacity method.

Currently, there is no established approach for the second measure, that of the *quality*, or enjoyment aspect of the walking environment. Several researchers and a number of planners have proposed qualitative measures of the *total quality* of the walking experience. Their approaches include numerous qualitative assessments relating to the pedestrian's *enjoyment* of the walking experience (e.g., convenience of the walking experience and the perception of personal security). Works by Sarkar (3,4), Khisty (5), Dixon (6), Crider (7), and others are examples of methods that include a mixed combination of some factors of all three performance measures. However, most of these methods require the presence of a sidewalk to be applicable. And, while the qualitative measure of a pedestrian's enjoyment of the walking experience is important to provide a complete picture of the walking environment and to design an "inviting" sidewalk, it is a separate measure of effectiveness and must be developed and

calibrated, if possible, separately from the sidewalk capacity or safety perception measures.

The third measure, the perceived safety or comfort (with respect to the presence of motor vehicle traffic) has not, until now), been quantified as a stand-alone performance measure. The common expression of pedestrians concerning how well a particular street or road accommodates their travel is from a perspective of safety and/or comfort. “It’s a dangerous place to walk” or “it’s fairly safe and comfortable” is the way they articulate their views of the roadway. This measure is the subject of our research, hence this paper. Considering only the roadway environment (i.e., excluding intersection conditions), the factors thought to *significantly* affect pedestrians’ sense of safety or comfort include:

- presence of a sidewalk
- lateral separation from motor vehicle traffic
- barriers and buffers between pedestrians and motor vehicle traffic
- motor vehicle volume and composition
- effects of motor vehicle traffic speed, and
- driveway frequency and access volume, among other factors.

The perception of safety and/or comfort is a qualitative measure of effectiveness recognized by the *1994 Highway Capacity Manual*. The *Manual* states (on pages 1-4 and 1-5), “*The concept of level-of-service uses qualitative (emphasis added) measures that characterize operational conditions within traffic the stream and their perception by (the facility users)...descriptions of individual levels of service characterize these conditions in terms of such factors as speed and travel time, freedom to maneuver,*

traffic interruptions, and comfort and convenience” (emphasis added) for the facility type.” With respect to measures of effectiveness, the *Manual* states, “For each type of facility, levels of service are defined on the basis of one or more operational parameters that best describe operating quality (emphasis added) for the facility type” (2). This is the direction of our (measure of effectiveness) effort to model the roadway walking environment.

Therefore, a calibrated, transferable model is needed to objectively reflect, “the perceived safety or comfort of pedestrians along a roadway segment” using measurable traffic and roadway variables. In response to this need, the *Pedestrian Level of Service Model* outlined herein has been developed. The *Model* is objective, transferable, and applicable at the roadway segment, and ultimately, when combined with an intersection level of service measure, applicable at the facility corridor and network levels. It evaluates roadside walking conditions *regardless* of the presence of a sidewalk. It can also demonstrate the impact of adding or improving sidewalks. It uses common, measurable traffic and roadway variables for economy of data collection, accuracy, and reliable and repetitive application. The *Model* is designed to evaluate a roadway segment; it does not include intersections and their complex conditions that are the subject of separate research initiatives.

DESIGN OF RESEARCH

This research initiative by the Florida Department of Transportation placed people in actual traffic and roadway conditions to obtain real-time feedback. Although a virtual reality, or simulation approach was briefly considered by the researchers due to its advantage of safety to the participants, it was not pursued because of the approach’s inability to include and/or replicate all response stimuli of the roadway environment.

Accordingly, 1) a special event was created to place a significant number of people on a walking course consisting of typical roadways in a typical U.S. metropolitan area, 2) obtain their real-time response to the roadway environment stimuli, and 3) create and test a mathematical relationship of measurable factors to reflect the Study participants' reactions. It should be noted that the research was designed to elicit responses from participants walking individually, not in pairs or groups. The following sections outline this approach.

Participants

Nearly 75 people participated in the first (i.e., the course-walking) portion of the study. The participants represented a broad cross section of age, gender, experience level, and geographic origin. Participants' ages ranged from 13 to 69. Due to the potential hazards of walking in urban-area motor vehicle traffic, children younger than age 13 were not permitted to participate. The gender split of the study group was forty-seven (47) percent female and fifty-three (53) percent male. The researchers and Sponsor sought participant diversity in both geographic origins and walking experience.

Accordingly, the study test course was located in Pensacola, Florida - a metropolitan area with significant in-migration. The average participant had lived in areas *other* than the Pensacola Bay region for the majority [approximately seventy-three (73) percent] of their life.

There was a considerable range of walking experience among the participants. There was a significant number who made relatively few walking trips (hence, mileage) and there were some who reported that they walked extensively virtually every day of

the week. Average distances walked per week ranged from a low of 1.6 kilometers (one mile) to a high of 79 kilometers (48 miles).

The Walking Course

A walking course was designed to subject the participants to a variety of traffic and roadway conditions. The course included road segments with traffic and roadway conditions typical of U.S. metropolitan areas. Approximately 8 km (5 mi) in length, the looped course consisted of 24 road segments (48 directional segments) with near equal lengths, but with varying traffic and roadway conditions. Although the majority of the segments were collector and arterial roads, some segments were local streets. During the walking event stage of the study, traffic volumes ranged from a low of 200 average daily traffic (ADT) to a high of 18,500 ADT. The percentage of heavy vehicles [as defined in the *Highway Capacity Manual* (2)] ranged from 0 to 3 percent. Traffic running speeds ranged from 25 to 125 km/hr (15 to 75 mi/hr). The roadway cross-sections included two to four lanes in forms of one way, undivided, divided, and continuous left-turn median lane configurations. The walking course included both curb and guttered as well as open shoulder cross-sectioned roadbeds. Some segments also had striped shoulders and some included designated bicycle lanes.

There were a variety of typical metropolitan area roadside conditions within the course. For example, some of the segments were urban in character with mixed combinations of on-street parking, landscaped buffers, street trees, and buildings adjoining the sidewalks with structures and awnings covering the sidewalks. Some segments were more suburban or rural in nature with roadside characteristics ranging

from no sidewalks to sidewalks directly adjoining the travel lanes, to sidewalks with intervening buffers of widths ranging from zero to twenty five (25) feet.

The walking course passed through a spectrum of land development forms and street network patterns found in the U.S. metropolitan areas. Retail commercial development forms ranged from large retail shopping centers to small convenience strip centers. Some segments had office buildings or other professional service establishments fronting them. Other land uses included churches, auto dealerships, banks, sit-down and fast-food restaurants with drive-throughs, professional and personal care businesses, car repair shops, and light industrial areas.

In the residential portions there was also an array of development forms directly adjoining the course. Residential dwellings included apartment and condominium units and other forms of attached dwelling units. Some course segments had single-family homes directly fronting them. Portions of the course passed through traditional grid street patterns; other parts ran through curvilinear street-forms. Neighborhoods represented a mix of income levels.

Participant Response

The real-time data collection activity of the study was promoted as an event entitled the *FunWalk for Science*, with prize drawings and gifts as incentives for participation. Volunteer participants were recruited using a broad-based, area-wide, multimedia approach that included newspaper notices and articles, radio announcements, and direct mailings by and to numerous organizations and businesses. Displays with brochure-registration forms were deployed at area retail sports outlets, health clubs, colleges, government office lobbies, major employers, and bicycle shops.

The need for a large number of volunteer walkers mandated a weekend testing period. Accordingly, the *FunWalk for Science* was scheduled for the morning of one of the busier (from a traffic-volume standpoint) Saturdays of the year in Pensacola, March 18th. To ensure that all participants experienced uniform motor vehicle traffic volumes, the event was run during a single time block in the mid-morning. The participants first updated or completed registration forms that included a variety of demographic questions. They were then briefed in groups as to the purpose and rules of walking the course. Following the briefings, walkers were then sent to two starters who released them onto the course individually at one-minute intervals, in opposite directions. Although the participants were briefed on the course configuration and had instructions for completing the response cards, course proctors were also deployed at strategic points throughout the course. The proctors consisted of staff from the West Florida Regional Planning Council, the Florida Department of Transportation, the University of Florida, SCI, Inc., and a number of regional bicycle and pedestrian coordinators from throughout Florida. The proctors ensured that temporal spacing between walkers was maintained and that the participants were independently completing the response cards as they walked each segment. Participants were encouraged to reflect on their accumulating experience and re-grade any previously walked segments as they proceeded through the course.

The study's purpose was to evaluate the quality, or level of service, of the roadway segments, not the intersections. Accordingly, the participants were instructed to disregard the conditions at intersections and their immediate approaches. They were also encouraged to exclude from their consideration the surrounding aesthetics. They were to include only conditions within, or directly adjoining, the right-of-way. The

participants evaluated on a 6-point (“A” to “F”) scale how safe / comfortable they felt as they traveled each segment. Level “A” was considered the most safe / comfortable (or least hazardous). Level “F” was considered the least safe / comfortable (or most hazardous).

REDUCTION AND ANALYSIS OF DATA

The study design yielded approximately 1700 initial observations coincident with a myriad of traffic and roadway conditions throughout the walking course. The resulting data was compiled into both spreadsheet and Statistical Analysis Software (SAS) program databases for extensive analyses. Response outliers and trends were identified resulting in 1250 observations and 21 roadway sections (42 directional segments) available for further analysis of the specific effect of traffic and roadway variables.

An interesting response trend was also identified, ultimately determined to be that of response (or scoring) fatigue. A slight diminishing scoring trend was evident. Course length was not a factor (the average total duration of the participant’s course experience was approximately 2 hours) due to the clearly constant slope of the response trend. Presentation order of the segments was not a source of the trend either, since the course presented a variety of traffic, roadway, and urban forms in a random distribution. Since the participants walked the course in two direction groups, the averaging of the responses allowed for removal of the fatigue trend, thus Pearson Correlations among the traffic and roadway variables and stepwise regression of the dependant variable was possible using the non-biased (averaged) responses for correlation.

MODEL DEVELOPMENT

Several Pearson Correlation analyses were run using the SAS program on a variety of traffic and roadway variables. Not surprisingly, several variables exhibited some co-linearity. However, the co-linearity was not enough to preclude the inclusion of some co-linear variables into the *Model* due to notable exceptions. For example, while in some cases the presence and width of sidewalks and buffers correlated with increasing speed, in many cases it did not, reflecting that the current practice of roadside design (and/or provision of sidewalks and buffers) is not consistent with providing a uniform level of pedestrian safety and comfort throughout transportation systems.

A “long list” of potential *primary* independent variables influencing pedestrians’ sense of safety or comfort within the roadway was generated, and then tested (along with numerous other potential factors) in the stepwise regression portion of the *Model’s* development. The long list was generated based on: 1) the results of the aforementioned Pearson Correlation analyses; 2) the variables (and model terms) identified by group consensus and confirmed during the development of the earlier *Roadside Pedestrian Conditions (RPC) Model* [developed for the Tampa metro area MPO’s *Hillsborough County MPO Pedestrian Plan (8)*], which is currently the basis for several major metropolitan area pedestrian plans; and 3) extensive iterative testing of segment groupings with common levels of independent variables [wherein additional variables were identified which potentially could further explain the variation of the dependant variable (the pedestrians’ ratings of safety / comfort)]. The resulting long list of primary factors included, *but was not limited to*:

- 1) Lateral separation elements between pedestrians and motor vehicle traffic, including,
 - Presence of sidewalk
 - Width of sidewalk
 - Buffers between sidewalk and motor vehicle travel lanes
 - Presence of barriers within the buffer area
 - Presence of on-street parking
 - Width of outside travel lane
 - Presence and width of shoulder or bike lane
- 2) Motor vehicle traffic volume
- 3) Effect of (motor vehicle) speed
- 4) Motor vehicle mix (i.e., percentage of trucks)
- 5) Driveway access frequency and volume

The factors listed above were considered the most probable *primary* factors affecting pedestrians' sense of safety. As such, they are the basis for the preliminary structure and testing of the *Pedestrian LOS Model* represented in the following mathematical expression:

$$\begin{aligned}
 \text{Pedestrian LOS} = & a_1 f(\text{lateral separation factors}) + a_2 f(\text{traffic volume}) \\
 & + a_3 f(\text{speed, vehicle type}) + a_4 f(\text{driveway access} \\
 & \text{frequency and volume}) + a_n f(x_n) + \dots + C
 \end{aligned} \tag{1}$$

The researchers conducted step-wise regression analyses using the 1315 real-time observations. Numerous variable transformations and combinations of the factors were tested. Table 1 shows the best model form and it's terms' coefficients and T-statistics. The correlation coefficient (R^2) of the best-fit model is 0.85 based on the

averaged observations from the 42 directional segments (see Figure 1 for a plot of predicted *Pedestrian LOS* versus mean observed values). The coefficients are statistically significant at the 95 percent level. Thus, the following *Model* was developed:

$$\begin{aligned} \text{Ped LOS} = & - 1.2021 \ln (W_{ol} + W_l + f_p \times \%OSP + f_b \times W_b + f_{sw} \times W_s) \\ & + 0.253 \ln (\text{Vol}_{15}/L) + 0.0005 \text{SPD}^2 + 5.3876 \end{aligned} \quad (2)$$

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)

f_{sw} = Sidewalk presence coefficient

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

W_s = Width of sidewalk (feet)

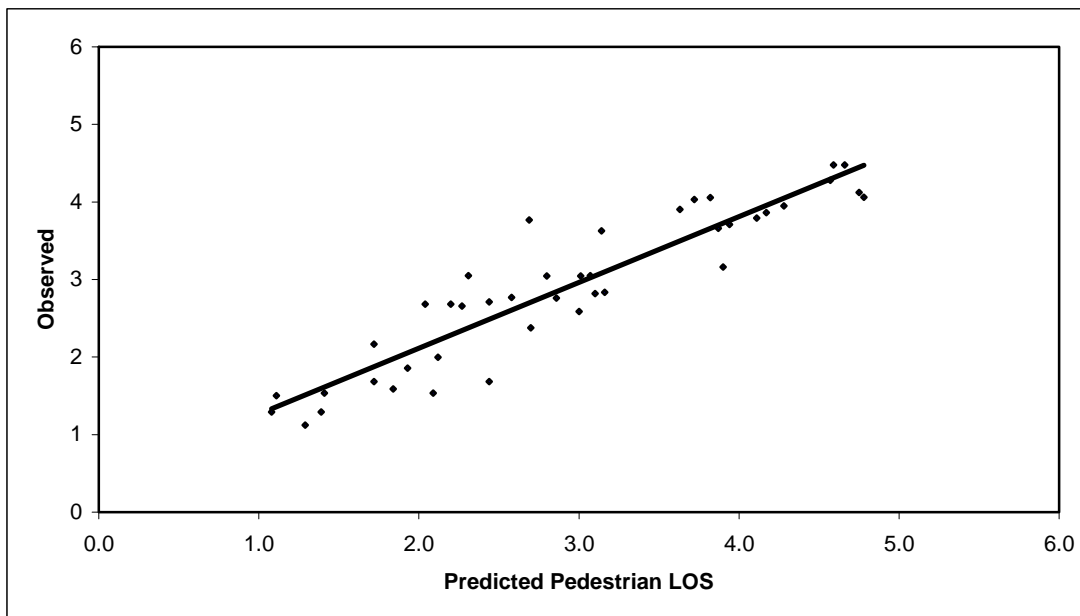
Vol_{15} = average traffic during a fifteen (15) minute period

L = total number of (through) lanes (for road or street)

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

TABLE 1 Model Coefficients and Statistics

Model Terms	Coefficients	T-statistics
Lateral Separation Elements: ln(LS)	- 1.2021	- 10.072
Motor Vehicle Volume: ln (Vol ₁₅ /L)	0.253	3.106
Speed and MV type: SPD ²	0.0005	2.763
Constant	5.3876	11.094
Model Correlation (R ²)	0.85	

**FIGURE 1 Residual plot of predicted and standardized residuals**

The *Pedestrian LOS Model* equation was created with a statistical significance at the 95% level. The factor, “driveway access frequency and volume”, while included in

the step-wise regression analyses, was not found to be statistically significant at that level.

Table 2 below may be used as a basis for stratifying the *Model's* numerical result into a pedestrian level of service class when it is applied to a particular roadway segment. It should be noted that this stratification was pre-determined as the responses gained in the Study were based on the standard U.S. educational system's letter grade structure (with the exception of Grade "E").

TABLE 2 Level of Service Categories

Level-of-Service	Model Score
A	≤ 1.5
B	> 1.5 and ≤ 2.5
C	> 2.5 and ≤ 3.5
D	> 3.5 and ≤ 4.5
E	> 4.5 and ≤ 5.5
F	> 5.5

Discussion of Model Terms

The terms of the calibrated model were developed and refined through extensive variables transformation testing and regression. The following briefly outlines some of the aspects of the terms and how the dependant variable responds to them.

Presence of a Sidewalk and Lateral Separation

Having a safe, separate place to walk alongside the roadway is fundamental in pedestrians' sense of safety and comfort in the roadway environment. This sense of safety or comfort is strongly influenced by the presence of a sidewalk. Furthermore, as

the calibrated *Model* confirms, the value of a sidewalk varies according to its location and buffering (i.e., the lateral separation) relative to the motor vehicle traffic. In general, as the lateral separation increases, the pedestrian's comfort or sense of safety also increases (see Figure 2). Additionally, when a barrier such as on-street parking, a line of trees, or a roadside swale is present in the buffer area between motor vehicle traffic and the pedestrian, the pedestrians' sense of protection, hence safety, is improved (see Figure 3). Finally, the *frequency* of parked cars, trees, or an increase in the depth of the intervening roadside swale would further improve the sense of safety.

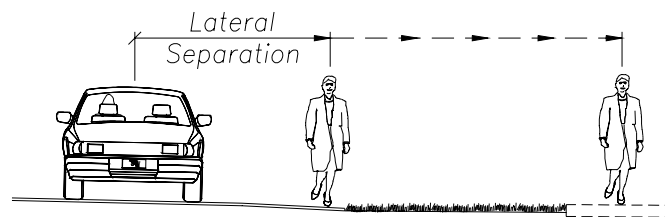


FIGURE 2 Effect of lateral separation.

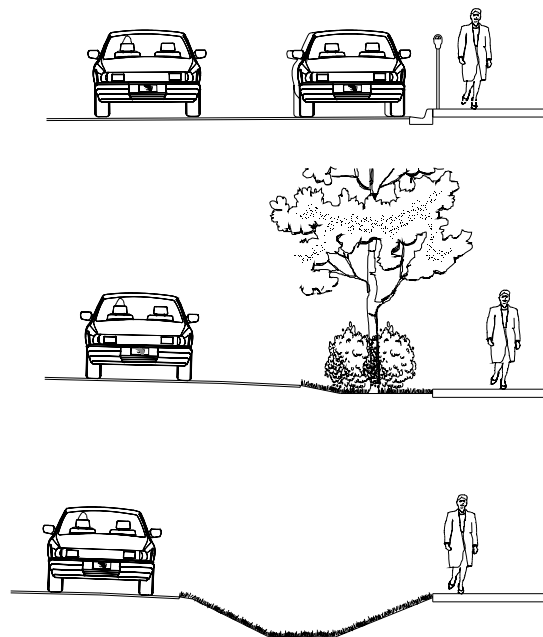


FIGURE 3 Typical barriers within the roadside buffer.

The mathematical expression that reflects these elements of lateral separation, barriers, buffers, and presence of a sidewalk is expressed as follows:

$$LS = W_{ol} + W_l + f_p \times \%OSP + f_b \times W_b + f_{sw} \times W_s \quad (4)$$

Where:

W_{ol} = Width of outside lane (feet)

W_l = Width of shoulder or bike lane (feet)

f_p = On-street parking effect coefficient

$\%OSP$ = Percent of segment with on-street parking

f_b = Buffer area barrier coefficients

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

f_{sw} = Sidewalk presence coefficient

W_s = Width of sidewalk (feet)

Examples of how the lateral separation elements are used to quantify some typical roadway cross-sections are illustrated below.

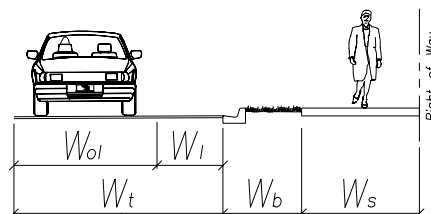


FIGURE 4 Buffers and sidewalk.

Figure 4 above shows a curbed cross-section with no vertical barriers in the horizontal buffer area between the travel lane and sidewalk. Note that there is no on-street parking, therefore the %OSP term equals zero. Thus for this scenario, the lateral separation term is given by:

$$LS = W_{ol} + W_l + f_b \times W_b + f_{sw} \times W_s \quad (5)$$

In the case where there is on-street parking, as is illustrated in Figure 5, its effect as a barrier is quantified as in Equation (6). Note that there is no striped shoulder or landscape buffer, therefore the W_l and W_b terms equal zero. Thus, the lateral separation term is simplified to:

$$LS = W_{ol} + f_p \times \%OSP + f_{sw} \times W_s \quad (6)$$

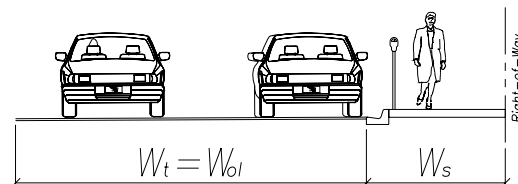


FIGURE 5 Lateral separation with on-street parking.

This section introduced the elements of lateral separation and their mathematical expression. The next sections describe the other two statistically-significant terms of the *Pedestrian LOS Model*.

Motor Vehicle Volume

The frequency of motor vehicles passing pedestrians, represented by the outside lane volume, was also found to be a significant factor. As passing frequency increases, the pedestrians' feeling of safety decreases. The effect of traffic volume is calculated by the following:

$$\text{Traffic Volume} = \frac{\text{Vol}_{15}}{L} \quad (7a)$$

where:

Vol_{15} = average traffic during a fifteen (15) minute period

L = total number of (thru) lanes (for road or street)

The equation above assumes a 50/50 directional distribution. In cases where the directional distribution is other than 50/50, equation 7b (below) should be used. The difference between the two is that equation 7b uses a directional factor and instead of using "L" (total number of thru lanes), it uses " L_d " (total number of *directional* thru lanes).

$$\text{Traffic Volume} = \frac{\text{Vol}_{15} \times D}{L_d} \quad (7b)$$

where:

Vol_{15} = average traffic during a fifteen (15) minute period

L_d = total number of directional (thru) lanes (for road or street)

D = directional factor

This effect on the walkers in the Study was found to be statistically significant. Transformations of this variable and subsequent stepwise regressions revealed that at lower traffic volumes, changes in the independent variable produced significant changes in the dependant variable. At higher volumes, however, there was less sensitivity; hence the natural log mathematical form of this term.

Effect of Speed

Similarly, the speed of motor vehicle traffic was confirmed as significantly affecting pedestrians' sense of safety. As speed increases, pedestrian discomfort increases. It was determined that the dependant variable had an exponential relationship with the average running speed of the motor vehicle traffic, somewhat similar to that relationship discovered during the development of the *Bicycle Level of Service Model (9)*, which has been incorporated into Florida's multi-modal level of service analysis guidelines (10).

Driveway Access Frequency and Volume

Along a roadway segment, uncontrolled vehicular access to adjoining properties (i.e., driveway cuts) was thought to reduce the pedestrian sense of safety. This transverse feature represents a similar "turbulence" or hazard to the pedestrian as to motor vehicle operators. Accordingly, as the number of driveways increases, a corresponding decrease in the perceived safety to the pedestrian was expected. Affecting this perception of safety is the volume of vehicles accessing the driveways. However, stepwise regression analyses revealed that this effect was not statistically significant at the 95 percent confidence level.

FINDINGS AND APPLICATIONS

The result of this initial research sponsored by the Florida Department of Transportation is the development of a reliable, statistically calibrated pedestrian level of service model suitable for application not only in Florida metropolitan areas, but also throughout North America. The *Pedestrian LOS Model* provides a measure of a roadway segment's performance with respect to pedestrians' primary perception of safety or comfort; as such it serves as the basis for the Florida Department of Transportation's state-wide multimodal (particularly for the pedestrian mode) level of service evaluation techniques. However, it can also be used to greatly influence roadway cross-sectional design and it can also help evaluate and prioritize the needs of existing roadways for sidewalk retrofit construction; applications for which the *Model's* precursor, the *Roadside Pedestrian Conditions Model*, has been successfully used. For example, transportation planners and engineers can now establish a target Pedestrian LOS and use the *Model* to test alternative roadway cross-section designs by iteratively changing the independent variables to find the best combination of factors to achieve the desired LOS. The *Model* thus provides roadway designers with solid guidance on how to better design pedestrian environments: how far sidewalks should be placed from traffic; when, and what type of buffering or protective barriers are needed; how wide the sidewalk should be; and etc. Finally, the *Pedestrian LOS Model*, when coupled with the *capacity* (Fruin) measure and a *quality* performance measure (i.e., a "Walkability Audit" to assess the enjoyment and convenience of the walking experience – in the case of an existing sidewalk) "completes the picture" of the roadside walking environment.

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TABLE TITLES AND FIGURE CAPTIONS

TABLE 1 Model Coefficients and Statistics

TABLE 2 Level of Service Categories

FIGURE 1 Residual plot of predicted and standardized residuals

FIGURE 2 Effect of lateral separation.

FIGURE 3 Typical Barriers within the Roadside Buffer.

FIGURE 4 Buffers and sidewalk.

FIGURE 5 Lateral separation with on-street parking.