Center for Pedestrian and Bicyclist Safety

A Tier-1 University Transportation Center

Pedestrian Level of Traffic Stress

July 2024

A Report From the Center for Pedestrian and Bicyclist Safety

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About the Center for Pedestrian and Bicyclist Safety (CPBS)

The Center for Pedestrian and Bicyclist Safety (CPBS) is a consortium of universities committed to eliminating pedestrian and bicyclist fatalities and injuries through cutting-edge research, workforce development, technology transfer, and education. Consortium members include: The University of New Mexico; San Diego State University; The University of California Berkeley; The University of Tennessee Knoxville; and The University of Wisconsin Milwaukee. More information can be found at: https://pedbikesafety.org

Disclaimer

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16. Abstract

This report presents a Pedestrian Level of Traffic Stress (PLTS) tool that can be used to represent how comfortable pedestrians feel around motor vehicle traffic on roadways. It is a project-scale tool that is typically applied within specific roadway corridors or neighborhood areas. PLTS has two components that assess how stressful it is for pedestrians to 1) travel along a roadway segment (segment PLTS) and 2) cross a roadway (crossing PLTS). The PLTS uses four categories (PLTS 1: Little to no stress; PLTS 2: Low stress; PLTS 3: Moderate stress; PLTS 4: High stress). In general, the lowest PLTS level is suitable for pedestrians of all abilities, including children, older adults, and people with disabilities. The highest PLTS level is likely to require sustained attention to the traffic situation and special ability to navigate safely. Inputs used to determine PLTS ratings are based on previous pedestrian suitability methods and key roadway characteristics associated with pedestrian injury risk. The following variables are used in segment PLTS: posted speed limit of adjacent roadway, motor vehicle traffic volume of adjacent roadway, sidewalk width, paved shoulder width, and buffer width between motor vehicle travel lane and pedestrian space. The following variables are used in crossing PLTS: posted speed limit of roadway being crossed, number of lanes being crossed, motor vehicle traffic volume of roadway being crossed, presence of traffic signal or pedestrian hybrid beacon (PHB) at the crossing, presence of stop sign at the crossing, presence of raised refuge island at the crossing, presence of curb extension(s) at the crossing, presence of rapid flashing beacons at the crossing, presence of high-visibility crosswalk marking at the crossing, and presence of accessible curb ramps at the crossing. PLTS should be complemented by other pedestrian analysis methods.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

Pedestrian Level of Traffic Stress

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Acronyms, Abbreviations, and Symbols

AADT	Annualized Average Daily Traffic
ADA	Americans with Disabilities Act
BLTS	Bicycle Level of Traffic Stress
FHWA	Federal Highway Administration
LTS	Level of Traffic Stress
NHTSA	National Highway Traffic Safety Administration
ODOT	Oregon Department of Transportation
PHB	Pedestrian Hybrid Beacon
PLTS	Pedestrian Level of Traffic Stress
WSDOT	Washington State Department of Transportation

Abstract

This report presents a Pedestrian Level of Traffic Stress (PLTS) tool that can be used to represent how comfortable pedestrians feel around motor vehicle traffic on roadways. It is a project-scale tool that is typically applied within specific roadway corridors or neighborhood areas. PLTS has two components that assess how stressful it is for pedestrians to 1) travel along a roadway segment (segment PLTS) and 2) cross a roadway (crossing PLTS). The PLTS uses four categories (PLTS 1: Little to no stress; PLTS 2: Low stress; PLTS 3: Moderate stress; PLTS 4: High stress). In general, the lowest PLTS level is suitable for pedestrians of all abilities, including children, older adults, and people with disabilities. The highest PLTS level is likely to require sustained attention to the traffic situation and special ability to navigate safely. Inputs used to determine PLTS ratings are based on previous pedestrian suitability methods and key roadway characteristics associated with pedestrian injury risk. The following variables are used in segment PLTS: posted speed limit of adjacent roadway, motor vehicle traffic volume of adjacent roadway, sidewalk width, paved shoulder width, and buffer width between motor vehicle travel lane and pedestrian space. The following variables are used in crossing PLTS: posted speed limit of roadway being crossed, number of lanes being crossed, motor vehicle traffic volume of roadway being crossed, presence of traffic signal or pedestrian hybrid beacon (PHB) at the crossing, presence of stop sign at the crossing, presence of raised refuge island at the crossing, presence of curb extension(s) at the crossing, presence of rapid flashing beacons at the crossing, presence of high-visibility crosswalk marking at the crossing, and presence of accessible curb ramps at the crossing. PLTS should be complemented by other pedestrian analysis methods.

Executive Summary

This report presents a Pedestrian Level of Traffic Stress (PLTS) tool that can be used to represent how comfortable pedestrians feel around motor vehicle traffic on roadways. It is a project-scale tool that can be applied within specific roadway corridors or neighborhood areas. PLTS has two components that assess how stressful it is for pedestrians to 1) travel along a roadway segment (segment PLTS) and 2) cross a roadway (crossing PLTS).

The PLTS uses four categories:

- PLTS 1: Little to no stress
- PLTS 2: Low stress
- PLTS 3: Moderate stress
- PLTS 4: High stress

In general, the lowest PLTS level is suitable for pedestrians of all abilities, including children, older adults, and people with disabilities. The highest PLTS level is likely to require sustained attention to the traffic situation and special ability to navigate safely.

The variables listed below are used to assign pedestrian traffic stress categories. They were selected based on previous pedestrian suitability methods and key roadway characteristics associated with pedestrian injury risk.

Variables used in segment PLTS:

- Posted speed limit of adjacent roadway
- Motor vehicle traffic volume of adjacent roadway
- Sidewalk width
- Paved shoulder width
- Buffer width between motor vehicle travel lane and pedestrian space

Variables used in crossing PLTS:

- Posted speed limit of roadway being crossed
- Number of lanes being crossed
- Motor vehicle traffic volume of roadway being crossed
- Presence of traffic signal or pedestrian hybrid beacon (PHB) at the crossing
- Presence of stop sign at the crossing
- Presence of raised refuge island at the crossing
- Presence of curb extension(s) at the crossing
- Presence of rapid flashing beacons at the crossing
- Presence of high visibility crosswalk marking at the crossing
- Presence of accessible curb ramps at the crossing

PLTS is intended for practical application, so its suitability categories are based on a small number of important roadway characteristics. PLTS should be complemented by other pedestrian analysis methods, such as an Americans with Disabilities Act (ADA) accessibility assessments, pedestrian crash analyses, pedestrian demand analyses, and social and economic environment assessments.

Section 1 of this report describes the purpose and origins of the PLTS tool. Section 2 presents the variables considered for the PLTS tool. Section 3 describes the PLTS tables and how to measure each of the input variables. Section 4 presents example applications of the PLTS tool.

Introduction

Most people travel as a pedestrian every day, including walking from home to work, school, shopping, or worship; walking for recreation; or walking to a parked car or bus stop (Schneider et al. 2019). Walking, including movement with assistive devices, is beneficial to both personal health and community wellbeing (Laird et al. 2018). With a growing emphasis on the importance of healthy, sustainable communities, efforts to understand pedestrian safety and comfort have increased significantly in the past 20 years (Schneider et al. 2019). Many cities, states, and other agencies have adopted pedestrian and bicycle plans, complete streets policies, and vision zero initiatives in attempts to improve the experience of all travelers. Traffic safety has been a significant component in many of these initiatives, and research on how to evaluate and improve pedestrian safety is continuing to develop.

As the body of research on active transportation modes grows, professionals have developed tools for evaluating the stress levels of road users like bicyclists and pedestrians—particularly as they interact with automobile traffic. In 2012, the Mineta Transportation Institute published a study on low-stress bicycle networks, creating a Bicycle Level of Traffic Stress (BLTS) evaluation tool (Mekuria, Furth, and Nixon 2012). The goal of their study was to create a resource that could quantify the level of stress a bicyclist may feel in different street environments in order to create connected networks of low stress facilities. This BLTS has become very popular in the profession since its introduction, being adopted and used by many municipalities and organizations.

While BLTS has gained widespread recognition in the profession, a similar tool for pedestrians has lagged behind in its development. Creating a standardized evaluation tool for pedestrian level of traffic stress (PLTS) is difficult, given the many built and social environment factors that influence pedestrians' experiences on streets. Further, the data needed to measure factors that could potentially be included in a PLTS framework may not be available in many communities. Municipalities also have different land use patterns, transportation systems, and cultural contexts, and may have different desires for how to address pedestrian infrastructure in their communities, as demonstrated by the different applications of the pedestrian suitability tools identified in our literature review.

Where PLTS tools have been created, there is a lack of consistency among them. This report presents a new, user-friendly PLTS tool by building on previous pedestrian suitability research and other existing PLTS tools.

Purpose of the PLTS Tool

The PLTS tool is intended to represent how comfortable pedestrians feel around motor vehicle traffic on roadways. PLTS has two components that assess how stressful it is for pedestrians to 1) travel along a roadway segment (segment PLTS) and 2) cross a roadway (crossing PLTS). Overall, segment PLTS and crossing PLTS are project-scale tools that can be applied to specific roadway corridors or neighborhoods. For communities seeking to assess PLTS throughout a large network, future iterations of PLTS could use a smaller subset of commonly-available roadway variables. The variables listed below are used to assign traffic stress categories in this project-scale version of PLTS. Asterisks indicate variables that could be excluded from future streamlined, network-scale versions of PLTS**.**

Traveling along roadway segments (segment PLTS):

- Posted speed limit of adjacent roadway
- Motor vehicle traffic volume of adjacent roadway
- Sidewalk width
- Paved shoulder width
- Buffer width between motor vehicle travel lane and pedestrian space*

Crossing roadways (crossing PLTS):

- Posted speed limit of roadway being crossed
- Number of lanes being crossed
- Motor vehicle traffic volume of roadway being crossed
- Presence of traffic signal or pedestrian hybrid beacon (PHB) at the crossing
- Presence of stop sign at the crossing
- Presence of raised refuge island at the crossing*
- Presence of curb extension(s) at the crossing*
- Presence of rapid flashing beacons at the crossing*
- Presence of high visibility crosswalk marking at the crossing*
- Presence of accessible curb ramps at the crossing*

PLTS is intended for practical application, so its suitability categories are based on only a small number of important roadway characteristics. For simplicity, it excludes many other roadway, behavior, and environmental factors that affect pedestrians' experiences in roadway environments. Therefore, PLTS is one component of a comprehensive pedestrian analysis. It should be complemented by other methods, such as:

- **Americans with Disabilities Act (ADA) Accessibility Assessment.** Audit street segments and crossings to ensure that pedestrians of all abilities are accommodated. Pedestrian facilities should meet or exceed ADA Accessibility Standards (US Access Board 2023).
- **Pedestrian Crash Analysis.** Compile and analyze pedestrian crash data, including pedestrian injury severity and crash types. When possible, conduct a systemic pedestrian safety analysis to identify roadway locations with a high risk of future crashes (Thomas et al. 2018). This type of analysis should assess roadway lighting and pedestrian crashes at night.

- **Pedestrian Demand Analysis.** Understand how pedestrian activity is distributed geographically throughout a community and when pedestrian activity occurs during the day, week, and year. Many pedestrian demand analysis methods have been developed (Schneider, Schmitz, and Qin 2021; Ryus et al. 2022).
- **Social and Economic Environment Assessment.** Gather information about community members' perceptions of social interactions, economic opportunities, and desires for improvements within roadway environments (Schneider, Weirs, and Schmitz 2022). This may include collecting and analyzing crime, business, or public survey data and considering differences between daytime and nighttime.

Since our project-scale PLTS captures a small, focused set of factors to represent pedestrians' perceptions of traffic safety in the roadway environment, these other techniques are also important for developing a more complete understanding of how pedestrians experience roadway networks.

Origins of the PLTS Tool

Our new PLTS tool builds on existing PLTS methods from the Oregon Department of Transportation (ODOT) (2020), the Washington State Department of Transportation (WSDOT) (2020), and the Montgomery County, Maryland Planning Department (2020). While many studies have identified built environment factors associated with pedestrian crashes, few have operationalized these factors into a straightforward, user-friendly metric that measures a pedestrian's level of stress in different walking environments. There is currently no simple, standard metric for evaluating pedestrian stress or comfort levels in the United States, though some state DOTs use the complex pedestrian level of service methods from the Highway Capacity Manual (National Academies of Sciences, Engineering, and Medicine 2022). Based on our review, only a few organizations in the United States like ODOT, WSDOT, and Montgomery County are using a PLTS approach to represent pedestrians' perceived safety with respect to roadway traffic. The PLTS methods used by ODOT, WSDOT, and Montgomery County were all created or updated in the past three years, and each one uses a slightly different set of factors to measure pedestrian levels of stress or comfort in walking environments. We provide a high-level summary of the ODOT, WSDOT, and Montgomery County PLTS methods below.

Oregon Department of Transportation (ODOT)

ODOT created a Pedestrian Level of Traffic Stress (PLTS) metric to compliment the Bicycle Level of Traffic Stress (BLTS) and other methods of evaluating the safety and comfort of transportation infrastructure. The PLTS tool developed by ODOT is different than many other methods of multimodal suitability analysis because it does not require a complex mathematical formula to use. ODOT has applied its BLTS analysis on the citywide scale to its capital city of Salem, Oregon using GIS mapping techniques; however, it has not yet done the same GIS analysis using its PLTS tool. Instead, individual segments have been evaluated using PLTS at a smaller scale.

ODOT's PLTS scoring system relies on several evaluation tables, and the final score is determined by the highest (most stressful) score produced from each step in the evaluation. This multi-step analysis process can be complex. It also overlooks some of the relationships between factors; for example, high traffic volume may yield a high stress level, but if there is a substantial buffer present, it may counteract that factor and reduce overall pedestrian stress.

ODOT appears to be leading in the development of a user-friendly PLTS tool. Their PLTS has been used as a baseline for other agencies such as Washington State DOT (WSDOT) and cities like Richardson, TX, which included a PLTS analysis in its recently adopted Active Transportation Plan (City of Richardson 2023).

Washington State Department of Transportation (WSDOT)

The ODOT PLTS metric was adapted by WSDOT to utilize data available at the statewide level, as the tool is intended to be used in the state's Active Transportation Plan. Due to the availability of statewide data, the PLTS metric used by WSDOT includes a smaller set of evaluation factors, and it closely mimics the BLTS tool. WSDOT (2022) updated its PLTS tool to include more factors related to the pedestrian experience. The original WSDOT PLTS tool only included speed and number of traffic lanes in its evaluation of roadway segments, but the recent update added sidewalk width, buffer type, and traffic volume. This update adds another step in the evaluation called the "Refined LTS," which adds several other factors for consideration on a case-by-case basis. After determining the initial level of traffic stress using the tables (considered "Basic LTS"), further review using the Refined LTS factors can be conducted to determine specific design changes. While these updates made the PLTS evaluation slightly more robust, WSDOT still does not have a PLTS tool to evaluate crossings.

Montgomery County (MD) Planning Department

Montgomery County Planning Department (2020) created a Pedestrian Level of Comfort Methodology as a component of its county-wide Pedestrian Plan in 2020. In contrast to the other two methods, Montgomery County's Pedestrian Level of Comfort (PLOC) strives to evaluate the perceived comfort of pedestrian infrastructure, extending beyond the minimum threshold of safety. As a result, this evaluation method includes factors that differ slightly from the PLTS tools by ODOT and WSDOT.

Previous Research: Factors Associated with Pedestrian Traffic Stress

In addition to building on the PLTS methods used by ODOT, WSDOT, and Montgomery County, our PLTS framework is rooted in a review of academic literature. It incorporates some of the most common variables from dozens of pedestrian suitability studies from around the world. However, to keep our PLTS framework practical to implement, we do not incorporate a number of complex or difficult-to-collect variables included in previous pedestrian suitability studies, though we cover some of these other variables in this literature review.

Researchers have recognized the association between roadway characteristics and pedestrian safety and comfort for many decades, but pedestrian suitability studies have flourished over the last 25 years (Landis et al. 2001; Baltes and Chu 2002; Campbell et al. 2003; Retting, Ferguson, and McCartt 2003; Petritsch et al. 2005; Raad and Burke 2018; Rodriguez-Valencia et al. 2022; World Health Organization 2023). Methods to evaluate pedestrian comfort have also been incorporated into the Highway Capacity Manual's Multimodal Level of Service approach (National Academies of Sciences, Engineering, and Medicine 2022).

We describe common variables associated with pedestrian suitability in the sections below. Table 1 summarizes common variables used to evaluate pedestrian stress levels on roadway segments in the ODOT, WSDOT, and Montgomery County PLTS methods. Table 2 summarizes common variables used to evaluate roadway crossings or intersections in these three PLTS methods. Table 3 outlines other common roadway segment and crossing variables found in our review of pedestrian suitability literature summaries.

Motorized Traffic Characteristics

Motorized traffic characteristics are often included in pedestrian suitability analyses from around the world. Two of the most common variables to assess pedestrian safety are traffic speed (Phillips & Guttenplan 2003; Krambeck 2006; Sisiopiku et al. 2007; Maghelal & Capp 2011; Raad & Burke 2018) and traffic volume (Maghelal & Capp 2011; Raad & Burke 2018; Nag et al. 2020). We chose to use both of these variables in our PLTS framework.

Traffic speeds are a critical factor for pedestrian stress, as higher speeds are associated with increased pedestrian crash risk (Sullivan and Flannagan 2007; Guerra et al. 2020) and more severe injuries when pedestrian crashes occur (Tefft 2013). As such, all of the evaluation metrics studied here include some measure of traffic speed in their analyses. ODOT and Montgomery County consider the prevailing speed, or the speed most drivers actually travel, instead of the posted speed limit when possible.

WSDOT and Montgomery County both use traffic volume as a factor to evaluate roadway segments, but each uses a different measurement for volume. WSDOT uses annualized average daily traffic (AADT). Generally, higher AADT measurements yield greater levels of stress for pedestrians. Montgomery County considers roadway functional classification as an alternative measure of traffic volume; classifications that tend to have lower traffic volumes have higher pedestrian comfort scores.

Roadway crossing suitability also tends to be assessed using traffic speeds and volumes. Length of crosswalk was also found as a variable in multiple studies (Sisiopiku et al. 2007; Maghelal & Capp 2011). However, pedestrian crossing suitability assessments were less common than assessments of walking along the roadway.

Roadway Cross-Section

Roadway cross-section characteristics include right-of-way width, curb-to-curb width, and number of lanes. The number of travel lanes was included in DOT evaluation metrics, but this attribute was not as common in academic reviews of pedestrian suitability studies. The ODOT PLTS uses the number of travel lanes as a proxy for traffic volume since actual traffic volume is not included as an input. WSDOT uses number of lanes as a separate factor in addition to AADT.

Pedestrian Pathways: Sidewalks, Sidepaths, Shoulders, and Buffers

Pathways adjacent to roadways include sidewalks, sidepaths, and paved shoulders. Common pedestrian pathway conditions used in pedestrian suitability analysis include the presence and width of the pathway. Sidewalk width was a common factor in the pedestrian suitability literature (Phillips & Guttenplan 2003; Sisiopiku et al. 2007; Maghelal & Capp 2011; Raad & Burke 2018; Nag et al. 2020). Width impacts the ability of pedestrians to move freely past one another. Wider sidewalks also allow pedestrians to walk further from moving traffic. Narrower sidewalks can also force pedestrians to walk closer to vehicle traffic, which can result in high levels of stress. Sidewalks that are 6 feet or greater in width tend to yield lower levels of stress or greater levels of comfort. Shoulder width was also found in the review of literature from studies in the US (Sisiopiku et al. 2007), but less common outside of the country (Raad & Burke 2018).

Montgomery County's PLOC includes separate evaluation tools for roadway segments with and without pedestrian pathways. The evaluation for "No Pathway" segments includes fewer factors, and most scores indicate high levels of stress. The best level of comfort cannot be achieved in this evaluation if there is no pedestrian pathway present.

Buffers between the pathway and travel lanes were considered in all PLTS metrics examined. However, each study defines and measures buffers slightly differently. ODOT uses different buffer types and buffer widths as factors to evaluate PLTS scores. The categories for buffer types include no buffer, solid surface (i.e., pavement with street furniture elements), landscaped with grass or low-lying vegetation, landscaped with trees, and vertical separation. According to this evaluation, vertical buffers and landscaping with trees produce the least amount of pedestrian stress, with low landscaping and solid surface buffers following closely behind. Width is evaluated separately and considers the width of the buffer itself, parking lanes, shoulders, and bike lanes in its measurement.

Montgomery County considers both buffer width and on-street buffer type in its PLOC evaluation. On-street buffer types include designated and marked parking lanes, one-way separated bike lanes, and two-way separated bike lanes. Buffer widths in this evaluation do not measure the on-street buffer, only the distance between the edge of the pedestrian path and the edge of the roadway.

In its updated PLTS metric, WSDOT separated buffers into two categories: robust physical barrier and wide sidewalk or sidewalk with buffer. A robust physical barrier can include a separated bike lane, planting strip, street trees, or a parking lane.

Surface Conditions and Aesthetics

Pedestrian pathway surface conditions (Phillips & Guttenplan 2003; Krambeck 2006; Sisiopiku et al. 2007; Raad & Burke 2018; Nag et al. 2020) and cleanliness (Krambeck 2006) have been used to determine pedestrian suitability. Physical pathway conditions may also include cross slope, loose pavement, cracking, or other surface inconsistencies. Montgomery County and ODOT have available data on sidewalk condition, so both use this as a factor in their evaluation tools. These variables require a large amount of fieldwork and surveys to collect. Therefore, surface conditions were not included in our PLTS framework. Further, other aesthetic characteristics were not included due to their difficulty to measure and frequent changes.

Pedestrian Volume

Pedestrian volume is included in many of the academic pedestrian suitability studies because, with the exception of very crowded areas, streets with more people are often more enjoyable and comfortable for pedestrians (Krambeck 2006; Sisiopiku et al. 2007; Maghelal & Capp 2011; Nag et al. 2020). A larger number of pedestrians may be associated with "safety in numbers" (Jacobsen 2015), so pedestrians may perceive roadway conditions to be safer. Note that pedestrian crowding, which occurs at very high pedestrian volumes, is another type of discomfort that pedestrians experience, but this is a different type of stress than traffic stress. Both Montgomery County and ODOT considered pedestrian volume in their PLTS evaluations. While pedestrian volume is associated with pedestrians' experience in the roadway environment, we did not include it in our PLTS method because it is difficult to collect and would add a high level of complexity to the assessment.

Land Use

Land use is analyzed in the ODOT PLTS and Montgomery County PLOC and is also found in studies from around the world (Krambeck 2006). In most pedestrian suitability applications, land use serves as a proxy for other conditions that are more difficult to measure.

ODOT considers four general land use categories to indicate overall "walkability" of a roadway segment based on the anticipated presence of pedestrians, number of destinations or attractions, building density, and exposure to noise, heavy vehicle use, or other stressful environmental conditions. The four land use groupings, from least stressful to most stressful, are generally categorized as follows:

- Residential, neighborhood commercial, business districts, and institutional
- Low density development, rural subdivisions, strip commercial, and other suburban/rural contexts
- Light industrial, big-box developments, and auto-oriented uses
- Heavy industrial and intermodal or freeway interchanges

Montgomery County uses land use in a similar, but more simplified way, categorizing land uses into "urban" or "non-urban." The purpose of this distinction is to predict the general pedestrian activity on a given roadway segment. Urban land uses are anticipated to have larger pedestrian volumes and therefore require wider pedestrian pathways to accommodate them. On the other hand, non-urban land uses are expected to have less pedestrian activity and thus, can use narrower pedestrian pathways without sacrificing pedestrian comfort.

For simplicity, we do not include land use in our PLTS framework. Our PLTS focuses on how pedestrians are likely to feel with respect to traffic crash risk, and pedestrian crowding and other pedestrian experiences impacted by adjacent land uses are different than traffic stress.

Table 1. Summary of roadway segment factors in existing Pedestrian Level of Traffic Stress (PLTS) tools

PLTS Tool	Traffic Speed	Traffic Volume	Roadway Cross-Section	Pathway/Sidewalk	Pathway Condition	Pedestrian Volume/Land Use
Oregon DOT Multimodal Analysis Methods	Prevailing or posted speed (≤25 mph, 30 mph, 35 mph, ≥40mph)		Used to imply traffic volumes and functional classification	Sidewalk effective width (accounting for obstructions) Buffer type	Pavement condition (“good-fair-poor” rating system)	General land use categories
Washington State DOT	Posted speed (≤ 25mph, 30-35mph, ≥40mph)	Annualized Average Daily Traffic (AADT)	Number of lanes (2 lanes or >2 lanes)	Sidewalk coverage (complete sidewalk on both sides, on one side, or no sidewalk). Sidewalk width not included due to lack of data	Pathway condition not included due to lack of data.	
Montgomery County Pedestrian Level of Comfort	Prevailing or posted speed, depending on data (<25 mph, 25 mph, 30 mph, 35 mph, ≥ 40 mph)	Functional roadway classification used as proxy for traffic volume		Sidewalk presence Sidewalk width On-street buffer type	Quality of pathway surface, considering obstructions and missing segments	Land use (urban or non-urban)

Table 2. Summary of roadway crossing or intersection factors in existing Pedestrian Level of Traffic Stress (PLTS) tools

PLTS Tool	Traffic Speed	Traffic Volume	Roadway Cross-Section	Traffic Control	Pedestrian Crossing Facilities	Pedestrian Volume/Land Use
Oregon DOT Multimodal Analysis Methods	Prevailing Speed or Speed Limit (≤25 mph, 30 mph, 35 mph, ≥ 40mph)	Vehicles per day for 2 total lanes (<5000, 5000-9000, >9000) Vehicles per day for 3+ total lanes (<8,000, 8,000-12,000, >12,000)	Total lanes crossed with no median (1 or 2+) Total lanes crossed with median refuge (1, 2, 3 or 4+)		Adjustments for Arterial Crosswalk Enhancements: Markings, signage, illumination or raised crosswalks	General land use categories
Washington State DOT		AADT (<10k or ≥10k)	Number of travel lanes (2, 3 or 4+)	Distance between signalized intersections (<600 ft, 600-1200 ft, >1200 ft)		
Montgomery County Pedestrian Level of Comfort	Highest posted speed (<25 mph, 25 mph, 30 mph, 35 mph, ≥40mph)		Number of travel lanes (1-3, 4-5, 6+)	Crossing control (Yes or no)	Crosswalk type (high-visibility, marked, unmarked) Median type (raised refuge, raised/hardened centerline, painted/none) Additional accessibility evaluation	Land use (urban or non-urban)

Table 3. Summary of Pedestrian Suitability Literature Reviews

General information		Methods		Common Variables or Factors Identified in Literature				Notes
Study Location(s)	Author(s)	Number of Studies Reviewed	Lit review approach	Land Use & Built Environment	Traffic Characteristics	Pathway Conditions	Other	Additional Details
7	Phillips & Guttenplan (2003)		Summarize types of quality of service and methodologies	• Lateral separation	• Ease of street crossing • Pedestrian signals • Traffic speeds	• Surface Condition	• Facility type	• Assessed multimodal quality of service including bicycle and public transit • Examined supply side assessments • Most studies fail to consider surrounding paths and trails
Field Tests in Beijing, Washington, Delhi and others	Krambeck (2006)	24 pedestrian audit and index methodologies	Analyze each methodology to develop a Global Walkability Index	• Surrounding Land Use Characteristics	• Traffic Speed • Crossing Safety	• Cleanliness	• Funding and resources • Perception of safety • Pedestrian Density	• Used to form conclusions on a broader area, not a specific segment • Requires field work and survey collection to grade the level of service (LOS)
Eight varying sidewalks in Alabama, US	Sisiopiku, Byrd & Chittoor (2007)	5 methods of evaluating level of service	Review and compare existing methods for establishing the quality of pedestrian sidewalks in an urban setting	• Sidewalk Space • Crossing opportunities • Buffer	• Traffic Speed	• Personal security • Pedestrian volume • Mix of Users	• Surface quality	• The same sidewalk may result in multiple LOS ratings • No method can capture all sidewalk factors in sufficient detail
Indices analyzing areas or Segments largely from the US	Maghelal & Capp (2011)	25 pedestrian suitability indices	Identify variables across studies and categorize each as objective, subjective, or distinctive as they apply to measuring in GIS	• Sidewalk Width • Location of Sidewalk • Length of Crosswalk	• Traffic Speed • Traffic Volume • Availability of Signals		• Population Density • Convenience	• Did not address the validity of indices, only compiled a list of variables. • Focused on aerial approaches and specifically in the lens of GIS applications.
Studies from around the world including a majority from the US	Raad & Burke (2018)	58 pedestrian level of service studies	Preferred Reporting Items for Systematic Review Recommendations (PRISMA) protocol	• Footpath width • Shoulder or buffer width • Lighting	• Traffic speed • Traffic Volume	• Footpath Condition	• User Characteristics	• Looked at studies for mixed use areas, footpaths, intersections, and mid-block crossings • Used a mix of quantitative and qualitative studies • Acknowledged little research for pedestrians with disabilities
Studies from around the world including US, eastern Asia, and Europe	Nag et al. (2020)	55 pedestrian level of service studies and 8 review papers	Compare and analyze the broad constructs and repeated attributes	• Width and Effective Width of Sidewalk • Number of Lanes • Presence of barrier	• Vehicle Volume	• User perception (aesthetics, and safety)	• Walking Speed • Pedestrian Density	• Included analysis from developing countries • Contained studies with data from as early as 1971. • Graded A through F

The Pedestrian Level of Traffic Stress (PLTS) Method

PLTS uses a small number of variables to represent how comfortable pedestrians feel around motor vehicle traffic on roadways. It is indented for application within specific roadway corridors or neighborhood areas, but communities with sufficient data could also apply the method to an entire roadway network. PLTS assesses how stressful it is for pedestrians to 1) travel along a roadway segment (segment PLTS) and 2) cross a roadway (crossing PLTS). Segment PLTS is based on five variables, and crossing PLTS is based on eight variables. This section presents tables that analysts can use to assign one of four PLTS categories to each segment or crossing.

PLTS Category Definitions

Following the approach used by the BLTS method and previous PLTS approaches, our PLTS framework assigns four pedestrian stress categories to each roadway segment or crossing. Our PLTS refines the definitions created by ODOT and also used by WSDOT in their PLTS tools. Maintaining some consistency between the existing PLTS analysis methods can be helpful for comparison and further research.

Our four PLTS categories are defined below. In general, the lowest PLTS level is suitable for pedestrians of all abilities, including children, older adults, and people with disabilities. The highest PLTS level is likely to require sustained attention to the traffic situation and special ability to navigate safely.

PLTS 1: Little to no stress

- Generally comfortable for all users
- Children and people with mobility and sensory limitations face few challenges using these facilities

PLTS 2: Low stress

- Generally comfortable for children over 10 years old and adults
- Children and people with mobility and sensory limitations may experience some challenges using these facilities

PLTS 3: Moderate stress

- Somewhat uncomfortable for able-bodied adults
- Children and people with mobility and sensory limitations may experience significant challenges using these facilities

PLTS 4: High stress

- Uncomfortable for most users
- Children and people with mobility and sensory limitations will typically want to avoid these facilities

Note that these definitions focus on different users and their perceptions of safety, but the PLTS score is assigned to the roadway segment or crossing itself. Individual pedestrians may feel different levels of stress in the same roadway environment simply based on their age, ability, stress tolerance, and many other personal characteristics. Since PLTS scores are assigned to the pedestrian facility, they give the analyst an understanding of how broad groups of users might feel in a particular environment, rather than defining the experience of each individual pedestrian.

Process of Assigning PLTS Categories

The PLTS and PLOC methods created by ODOT, WSDOT, and Montgomery Planning Department provided guidance for the new PLTS tool created in this study. After analyzing these methods and a few other studies, factors that were present across all studies were identified as primary factors. Each primary factor was evaluated individually first, defining thresholds within that factor to understand how different conditions affect PLTS (e.g., the factor of traffic speed was broken into four speed categories, and each was assigned a PLTS score.) These primary factors were then combined until all primary factors were incorporated into a PLTS table. These initial tables were reviewed by experts, and in some cases, secondary factors were incorporated. Since the pedestrian experience differs between roadway segments and intersection crossings, these two environments are analyzed separately.

Variables Used in Segment PLTS

The PLTS input variables for roadway segments can be gathered for each side of the roadway. However, for simplicity, the roadway segment PLTS is expected to be applied by assigning the highest stress level from either side of the roadway. For streets with sidewalks or sidepaths only on one side, this is typically the side of the street without a designated pedestrian pathway.

Sidewalk Presence & Width

Pedestrian pathways, which are most often sidewalks, are the designated infrastructure for pedestrians to walk or roll alongside vehicular traffic. In many rural and suburban areas, paved shoulders function as pedestrian pathways. Sidewalk presence and width are both considered here. For PLTS, the width measurement is the effective sidewalk width, which only includes the clear zone that is unobstructed by plantings, street furniture, light poles, or other obstacles that significantly obstruct a pedestrian’s walking path. For sidewalks immediately adjacent to buildings, a two-foot frontage zone should not be included in the effective sidewalk width.

Adhering to guidelines set by the Americans with Disabilities Act (ADA), many agencies seek to create sidewalks that are a minimum of 5 feet wide (FHWA 2017). This allows pedestrians using wheelchairs to make a full rotation or pass one another without conflict. Since 5 feet is the minimum requirement for accessibility, it is given the highest PLTS score when evaluated individually. Organizations like the National Association of City Transportation Officials (NACTO) (2013) suggest that sidewalks have at least 6 feet of effective width for comfortability, with the caveat that sidewalk width should be based on expected pedestrian volumes. NACTO further suggests that sidewalks located directly alongside traffic be at least 8 feet wide. Sidewalks that are greater than 10 feet wide are considered to be the least stressful for all users.

Buffer Width

Buffer width is measured as the distance between the outside edge of the roadway space designated for motor vehicle movement (e.g., a travel lane or turning lane) and the pedestrian clear zone. Wider buffers typically result in lower stress levels since they reduce the risk of conflict with traffic and allow pedestrians to pay less attention to the traffic situation. Buffers also allow room for passing other pedestrians if necessary. A variety of different types of features can be present within buffer space, including parked cars, trees and other landscaping, bollards, utility poles, bioswales, and street furniture. Elements that provide stronger barriers between moving vehicle traffic and pedestrians typically produce lower levels of pedestrian stress. However, for simplicity of data collection, the width of the buffer is the only buffer attribute used to assess PLTS.

Dedicated bus lanes and bike lanes are considered to be part of the buffer, so they are included in the buffer width measurement. This is because most dedicated bus lanes will only be used by buses once every few minutes, and bicycles typically travel slower and are less threatening to pedestrians then motor vehicles. However, if these lanes are routinely used by other motor vehicles, they should not be counted in the buffer width measurement.

Traffic Speed

Research shows that increased traffic speeds lead to higher risk for pedestrian injury and fatality due to a crash. The risk level more than doubles when speeds increase from 20 mph to 30 mph. Almost 70% of pedestrians are severely or fatally injured in crashes with the vehicle traveling over 35 mph (Sandt et al. 2020). Because traffic speed is a factor that can vary based on street design and other contextual characteristics, prevailing 85th percentile speed should be used for this evaluation. If there is no available data on prevailing 85th percentile speed, it can be estimated from the posted speed limit (e.g., if the 85^{th} percentile speed is typically 5 mph higher than the posted speed limit on a sample of streets, then this assumption can be applied more broadly).

Traffic Volume

Based on our initial review of existing PLTS methods, traffic volume was identified as a secondary factor that was not considered in all studies. However, we chose to include traffic volume in PLTS because it can impact the pedestrian experience in a way not described by the first three factors. As such, this factor was incorporated by creating parallel PLTS tables whose only difference is traffic volume.

Variables used in Crossing PLTS

The PLTS input factors for roadway crossings can be gathered for individual crossing locations, including separate evaluations for each leg of an intersection or mid-block crosswalk. However, for simplicity, the roadway crossing PLTS is expected to be applied at the intersection level by assigning the highest stress level from any of the individual roadway crossings to the intersection as a whole. This is typically a crossing of the intersecting roadway with the highest traffic volume.

Number of Lanes
Crossing distance is a significant factor related to pedestrian stress when crossing streets. This factor is represented by the total number of traffic lanes, including through lanes and turning lanes, which is typically easier information to collect than specific measured width. The number of lanes also represent potential points of conflict with traffic. For this reason, turning lanes and other lanes being used for vehicular travel should be included in the lane count. Dedicated parking lanes, bicycle lanes, bus lanes or zones where vehicles are not traveling should not be included in the lane count.

Traffic Volume
Traffic volume is a significant factor for pedestrian crossings, especially those with less traffic control, because it impacts gaps between traffic and the likelihood of conflict with traveling vehicles. Low traffic volume streets, such as residential streets, typically require less attention from the pedestrian because there are fewer vehicles in the roadway. Higher volume streets may present challenges to pedestrians because they may have to find a gap in a stream of traffic in order to cross without conflict. At crossings with greater traffic control and high traffic volumes, there are often more potential conflicts due to higher turning movement volumes. As such, the two sets of PLTS tables for crossings are divided into three parallel tables ranging from low to high traffic volumes.

Traffic Speed
Traffic speed is critical for crossing safety because of its strong relationship with injury risk. Higher-speed roadways are perceived as more stressful for pedestrians because of the potential for high-energy impact and because it can be more difficult to identify gaps in traffic when vehicles are traveling faster. Traffic speed is especially important for crossings that have little to no traffic control because motorists are likely to be traveling at full speed while approaching the pedestrian crossing. For this reason, speed was used in the tables including no traffic control or rapid flashing beacons only. For crossings that take place at a signalized intersection, vehicle traffic is more likely to stop or yield regardless of pedestrian presence. As for roadway segment PLTS, prevailing 85th percentile speed (or an estimate of it) should be used for this evaluation.

Traffic Control
The type of traffic control implemented at crossings has an impact on pedestrian stress because it can affect the likelihood that motorists will stop or yield to pedestrians. Additionally, some traffic controls require motorists to stop regardless of pedestrian presence, while others require pedestrians to be present in order for motorists to stop or yield. In this study, traffic signals, stop signs, pedestrian hybrid beacons (PHBs), rapid flashing beacons (RFBs), and no control are considered in the crossing evaluation. The first three control types require motorists to stop when indicated, so they are evaluated in a separate set of tables. Rapid flashing beacons, while more helpful than no traffic control, only require motorists to stop or yield when pedestrians are present. In locations where pedestrian controls like RFBs are not common, motorists may not be aware they have to yield and will fail to do so. This puts pressure on pedestrians to pay more attention to the traffic situation and assess whether motorists will yield to them or not. Due to these strenuous

conditions, RFBs and no traffic control are considered separately, with additional factors like speed incorporated into the evaluation.

Crossing Treatments

In general, different types of pedestrian crossing treatments provide different levels of protection for pedestrians. The treatments selected in this evaluation include raised median refuge islands, curb extensions, and high visibility crosswalk markings. Some crossings, such as those at uncontrolled intersections, have no crosswalk markings or treatments, so “None” is included in this category as well.

High-visibility markings consist of ladder, continental, and zebra patterns painted in the crosswalk. Transverse crosswalks, or solid bars running perpendicular to the flow of vehicular traffic, are not considered high visibility markings because they are difficult for motorists to see when approaching the crossing (McGrane and Mitman 2013).

Raised median refuge islands are typically made of concrete and act as a physical barrier on both sides of the pedestrian crossing, offering protection from vehicles. These are often located at the mid-point of the crossing, which can be valuable for wide streets with multiple lanes because they provide a protected resting spot for pedestrians to pause midway through the crossing. To be considered as a PLTS crossing treatment, refuge islands should be at least 6 feet wide and have a physical form of protection (i.e., a raised concrete median.)

Curb extensions, or bump outs, reduce the crossing width for pedestrians by extending the edge of the curb into the street. These often take up space in the roadway that is dedicated to on-street parking lanes. Curb extensions also offer the benefit of visibility, indicating to motorists that they are approaching a pedestrian crossing.

Accessible Curb Ramps

Accessible curb ramps are essential roadway crossing facilities for pedestrians of all abilities and are required by the Americans with Disabilities Act. For some people, not having a curb ramp will completely prevent them from being able to cross a roadway at a specific location. Therefore, any crossing without accessible curb ramps is automatically given a stress rating of PLTS 3 or worse.

Factors Not Included in Pedestrian Level of Traffic Stress

There are several other factors that were either included in other studies or brought up as a part of this research that were not used in the final PLTS evaluation. These factors are worth discussing because, even though they were not chosen for this evaluation, they can impact the pedestrian experience.

Pedestrian Volume and Land Use

Both Montgomery County and ODOT considered pedestrian volume in their PLTS evaluations, using land use as a proxy for this factor. Land use can indicate the number and types of trips produced on a site, including walking trips. Urban design characteristics like building setbacks, building height, and street level activation can be inferred from general land use categories as well. These elements can contribute to an environment that fosters safer street behavior. In ODOT's evaluation, it is assumed that land uses that attract higher pedestrian volumes will result in safer driving behaviors. With large volumes of pedestrians, motorists may be more inclined to yield when necessary.

Pedestrian volume is closely related to other factors that were chosen for evaluation. Sidewalk widths should be large enough to accommodate the anticipated pedestrian volume of a street segment. The type of traffic control at crossings should be selected to fit the appropriate volume of people at crossings. While pedestrian volume is clearly relevant to pedestrian stress levels, pedestrian volume data are scarce. This is likely why ODOT and Montgomery County use land use as an indicator of pedestrian volume, because data on actual volumes is often not documented on a large scale.

One-Way Traffic

One-way streets may be easier for pedestrians to cross because they only need to look in one direction for traffic. However, depending on the overall number of lanes and roadway design, they may also facilitate higher traffic speeds. For simplicity, we do not include one-way versus two-way traffic in our PLTS.

Lighting

Darkness has a major impact on the pedestrian experience, limiting the ability of motorists to see pedestrians and pedestrians to make eye contact with drivers and accurately detect vehicle speed. Because of this, walking at night may be more difficult and stressful for pedestrians. In general, pedestrian scale lighting is important for illuminating pedestrians and their street environments at night. Lighting is a complex factor, however, with a variety of different metrics used to describe its quality. This makes it difficult to use as a simple factor in this PLTS evaluation.

Sidewalk Condition

The condition of the sidewalk, including the pavement quality, physical obstructions, cross slope, and other characteristics, has a significant impact on the accessibility of a roadway segment. For pedestrians using wheeled mobility devices or those who are simply less stable, a crack or fault in the sidewalk surface can present major challenges. Other obstructions like utilities in the sidewalk can decrease accessibility as well. Even for pedestrians without mobility challenges, these elements can cause tripping hazards and make the walking environment uncomfortable in general.

While this factor has a clear effect on pedestrian stress and comfortability, collecting data on specific sidewalk conditions is very labor and time intensive. These conditions can also change relatively quickly, requiring even more frequent data collection. Not many municipalities actively collect this information on a city-wide or regional basis, so this factor was not included in the PLTS evaluation.

Pollution
Many types of environmental conditions are likely to influence pedestrian stress levels. These include noise, smell, and air pollution. Since these factors are not directly associated with pedestrian crash risk, they are excluded from the PLTS.

Personal Security
In addition to wanting to be safe from motor vehicle traffic, pedestrians want to feel safe around other people as they walk along and across streets. Streets where pedestrians experience or perceive the risk of harassment, assault, or other street crimes are more stressful than streets that have a positive social environment. However, this particular PLTS focuses on traffic safety, so personal security is excluded from this method and should be analyzed in other ways.

Pedestrian Level of Traffic Stress (PLTS) Tables

This section presents the tables that are used to evaluate segment PLTS and crossing PLTS. Explanations of the data inputs used in the tables are provided in the previous section.

PLTS Tables for Roadway Segments (Segment PLTS)

There are two types of tables for roadway segments; see the guidelines below to select the appropriate table:

- For segments with **no sidewalk**, use Table 4.
- For segments **with a sidewalk**, use Tables 5-7.

Table 4. Pedestrian LTS for Roadway Segments with No Sidewalk

No Sidewalk		
Speed[1]	Shoulder (≥8ft)	No Shoulder
≤ 15mph	1	2
16-25mph	3	3
> 25mph	4	4

[1] Prevailing (actual) 85th percentile speed should be used if available data exists. If not, use an estimate of prevailing speed based on the posted speed limit.

Table 5. Pedestrian LTS for Roadway Segments with Sidewalks: Low Traffic Volume (< 2,500 AADT)

		Buffer Width			
Speed	**Sidewalk Width**	> 10ft	5ft to 9ft	1ft to 4ft	None
≤ 20mph	> 10ft	1	1	1	1
	8ft to 10ft	1	1	1	1
	5ft to 7ft	1	1	2	2
	<5ft	2	2	2	3
21-25mph	> 10ft	1	1	1	2
	8ft to 10ft	1	1	2	2
	5ft to 7ft	1	2	2	3
	<5ft	2	3	3	4
26-30mph	> 10ft	1	1	2	2
	8ft to 10ft	1	2	2	3
	5ft to 7ft	1	2	2	3
	<5ft	2	3	3	4
31-35mph	> 10ft	1	1	2	2
	8ft to 10ft	1	2	2	3
	5ft to 7ft	2	3	3	4
	<5ft	3	3	4	4
> 35mph	> 10ft	1	2	3	3
	8ft to 10ft	2	2	3	3
	5ft to 7ft	3	3	4	4
	<5ft	4	4	4	4

Table 6. Pedestrian LTS for Roadway Segments with Sidewalks: Medium Traffic Volume (2,500-7,500 AADT)

		Buffer Width & Type			
Speed	**Sidewalk Width**	> 10ft	5ft to 9ft	1ft to 4ft	None
≤ 20mph	> 10ft	1	1	1	2
	8ft to 10ft	1	1	2	2
	5ft to 7ft	2	2	2	2
	<5ft	2	3	3	3
21-25mph	> 10ft	1	1	2	2
	8ft to 10ft	1	1	2	3
	5ft to 7ft	1	2	2	3
	<5ft	3	3	3	4
26-30mph	> 10ft	1	1	2	3
	8ft to 10ft	1	2	2	3
	5ft to 7ft	2	2	3	4
	<5ft	3	3	4	4
31-35mph	> 10ft	1	2	3	3
	8ft to 10ft	2	2	3	4
	5ft to 7ft	3	3	4	4
	<5ft	3	4	4	4
> 35mph	> 10ft	1	2	3	3
	8ft to 10ft	2	2	3	4
	5ft to 7ft	3	3	4	4
	<5ft	4	4	4	4

Table 7. Pedestrian LTS for Roadway Segments with Sidewalks: High Traffic Volume (> 7,500 AADT)

		Buffer Width			
Speed	**Sidewalk Width**	> 10ft	5ft to 9ft	1ft to 4ft	None
≤ 20 mph	> 10ft	1	1	2	2
	8ft to 10ft	1	2	2	3
	5ft to 7ft	2	2	3	4
	<5ft	3	3	4	4
21-25mph	> 10ft	1	1	2	2
	8ft to 10ft	1	2	3	3
	5ft to 7ft	2	3	3	4
	<5ft	3	4	4	4
26-30mph	> 10ft	1	1	2	3
	8ft to 10ft	1	2	2	3
	5ft to 7ft	2	3	3	4
	<5ft	3	4	4	4
31-35mph	> 10ft	1	2	3	3
	8ft to 10ft	2	3	3	4
	5ft to 7ft	3	3	4	4
	<5ft	4	4	4	4
> 35mph	> 10ft	2	2	3	3
	8ft to 10ft	2	3	3	4
	5ft to 7ft	3	4	4	4
	<5ft	4	4	4	4

PLTS Tables for Roadway Crossings (Crossing PLTS)

There are two sets of tables for roadway crossings, differentiated by the presence of traffic control. See the guidelines below to select the appropriate table:

- For roadway crossings with traffic control (e.g., have a **traffic signal**, **stop sign**, or **pedestrian hybrid beacon**), use Tables 8-10.
- For uncontrolled roadway crossings (e.g., have **rapid flashing beacons** or **no traffic control**), use Tables 11-13.

Note that any crossing without accessible curb ramps will automatically have a minimum PLTS score of 3.

Table 8. Pedestrian LTS for Controlled Roadway Crossings: Low Traffic Volume (< 2,500 AADT)

		Crossing Treatments			
Traffic Control	**Crossing Width**	Raised Refuge Island AND Curb Extension(s)[2]	Raised Refuge Island only	Curb Extension only	None
Traffic Signal	1-2 lanes	1	1	1	1
	3 lanes	1	1	2	2
	4 lanes	2	2	2	2
	5+ lanes	2	3	3	3
Stop Sign	1-2 lanes	1	1	1	1
	3 lanes	1	1	2	2
	4+ lanes	2	2	3	3
Pedestrian Hybrid Beacon	1-2 lanes	1	1	1	1
	3 lanes	1	1	1	2
	4+ lanes	2	2	2	3

[2] Raised refuge islands must be 6 feet wide with a physical (raised) barrier.

Table 9. Pedestrian LTS for Controlled Roadway Crossings: Medium Traffic Volume (2,500-7,500 AADT)

		Crossing Treatments			
Traffic Control	**Crossing Width**	Raised Refuge Island AND Curb Extension(s)	Raised Refuge Island only	Curb Extension only	None
Traffic Signal	1-2 lanes	1	1	1	2
	3 lanes	1	1	2	2
	4 lanes	2	2	3	3
	5+ lanes	3	3	3	4
Stop Sign	1-2 lanes	1	1	1	2
	3 lanes	1	2	2	2
	4+ lanes	2	2	3	3
Pedestrian Hybrid Beacon	1-2 lanes	1	1	1	2
	3 lanes	1	1	2	2
	4+ lanes	2	2	3	3

Table 10. Pedestrian LTS for Controlled Roadway Crossings: High Traffic Volume (> 7,500 AADT)

		Crossing Treatments			
Traffic Control	**Crossing Width**	Raised Refuge Island AND Curb Extension(s)	Raised Refuge Island only	Curb Extension only	None
Traffic Signal	1-2 lanes	1	1	2	2
	3 lanes	1	2	2	2
	4 lanes	2	3	3	3
	5+ lanes	3	3	4	4
Stop Sign	1-2 lanes	1	1	2	2
	3 lanes	2	2	3	3
	4+ lanes	2	3	4	4
Pedestrian Hybrid Beacon	1-2 lanes	1	2	2	2
	3 lanes	2	3	3	3
	4+ lanes	3	3	4	4

Table 11. Pedestrian LTS for Uncontrolled Roadway Crossings: Low Traffic Volume (< 2,500 AADT)

Traffic Control	Traffic Speed[3]	Crossing Width	Crossing Treatment: Raised Refuge Island AND Curb Extension(s)	Raised Refuge Island OR Curb Extension(s) Only	High Visibility Crosswalk Marking Only[4]	None
Rapid Flashing Beacons	≤ 20mph	1-2 lanes	1	1	1	1
		3 lanes	1	1	1	2
		4+ lanes	2	2	2	2
	21-25mph	1-2 lanes	1	1	1	2
		3 lanes	1	1	2	2
		4+ lanes	2	2	3	3
	26-30mph	1-2 lanes	1	2	2	2
		3 lanes	2	2	2	3
		4+ lanes	2	3	3	4
	> 30mph	1-2 lanes	1	2	2	3
		3 lanes	2	2	3	3
		4+ lanes	3	3	3	4
No Traffic Control	≤ 20mph	1-2 lanes	1	1	1	2
		3 lanes	1	2	2	2
		4+ lanes	2	2	3	3
	21-25mph	1-2 lanes	1	1	2	2
		3 lanes	1	2	3	3
		4+ lanes	2	2	3	3
	26-30mph	1-2 lanes	1	2	3	3
		3 lanes	2	3	3	3
		4+ lanes	2	3	4	4
	> 30mph	1-2 lanes	2	2	2	3
		3 lanes	2	3	3	4
		4+ lanes	3	3	4	4

[3] Prevailing (actual) 85th percentile speed should be used if available data exists. If not, use an estimate of prevailing speed based on the posted speed limit.
[4] High visibility crosswalks include continental, ladder, and zebra style markings. Solid bars that run perpendicular to traffic are not considered to be high visibility markings.

Table 12. Pedestrian LTS for Uncontrolled Roadway Crossings: Medium Traffic Volume (2,500-7,500 AADT)

Traffic Control	Traffic Speed	Crossing Width	Crossing Treatment			
			Raised Refuge Island AND Curb Extension(s)	Raised Refuge Island OR Curb Extension(s) Only	High Visibility Crosswalk Marking Only	None
Rapid Flashing Beacons	≤ 25mph	1-2 lanes	1	1	1	2
		3 lanes	1	2	2	2
		4+ lanes	2	2	3	3
	26-30mph	1-2 lanes	1	2	2	3
		3 lanes	2	2	3	3
		4+ lanes	2	3	3	4
	> 30mph	1-2 lanes	2	2	2	3
		3 lanes	2	3	3	4
		4+ lanes	3	3	4	4
No Traffic Control	≤ 25mph	1-2 lanes	1	1	2	2
		3 lanes	1	2	3	3
		4+ lanes	2	2	3	3
	26-30mph	1-2 lanes	1	2	3	3
		3 lanes	2	3	3	3
		4+ lanes	2	3	4	4
	> 30mph	1-2 lanes	2	2	3	3
		3 lanes	3	3	3	4
		4+ lanes	3	4	4	4

Table 13. Pedestrian LTS for Uncontrolled Roadway Crossings: High Traffic Volume (< 7,500 AADT)

Traffic Control	Traffic Speed	Crossing Width	Crossing Treatment			
			Raised Refuge Island AND Curb Extension(s)	Raised Refuge Island OR Curb Extension(s) Only	High Visibility Crosswalk Marking Only	None
Rapid Flashing Beacons	≤ 25mph	1-2 lanes	1	2	2	2
		3 lanes	2	2	3	3
		4+ lanes	2	3	3	4
	26-30mph	1-2 lanes	2	2	2	3
		3 lanes	2	3	3	3
		4+ lanes	3	3	4	4
	> 30mph	1-2 lanes	2	2	3	3
		3 lanes	3	3	3	4
		4+ lanes	3	4	4	4
No Traffic Control	≤ 25mph	1-2 lanes	2	2	2	3
		3 lanes	2	2	3	3
		4+ lanes	3	3	3	4
	26-30mph	1-2 lanes	2	2	2	3
		3 lanes	2	3	3	3
		4+ lanes	3	4	4	4
	> 30mph	1-2 lanes	2	3	3	3
		3 lanes	3	3	4	4
		4+ lanes	4	4	4	4

Example PLTS Applications

Our PLTS is intended for evaluating pedestrian stress in roadway corridors or small areas, such as neighborhoods or small cities. This section presents several examples of PLTS applications to illustrate its usefulness for pedestrian suitability analysis.

Example 1: Area application (Shorewood, WI)

To show how PLTS can be applied to a small area, we use Shorewood, WI (population 12,000) as an example (Figure 1). Figure 1 displays the segment PLTS for each street segment. To assign one PLTS score to each road segment, the conditions on both sides of the street had to be considered, even if they were slightly different. We can see several patterns in this map: the arterial and collector streets that run through the Village tend to have higher stress levels than residential streets. These streets also have the highest traffic volumes.

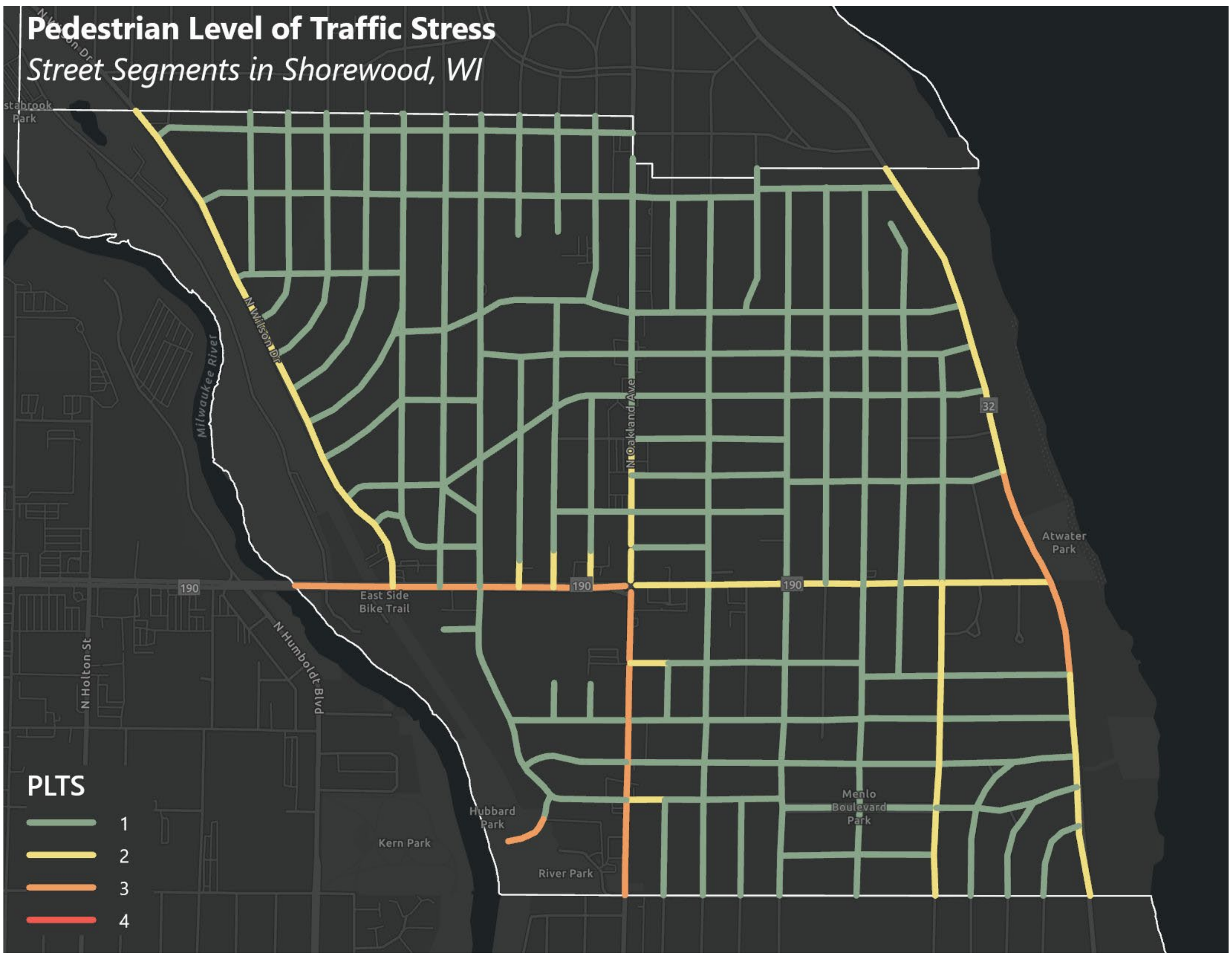


Figure 1. Segment PLTS ratings in Shorewood, WI

The crossing PLTS was applied to crossings in the southwest part of Shorewood (Figure 2). A similar pattern of higher stress levels can be seen in this evaluation, with crossings on Capitol Drive and Oakland Avenue being PLTS 3 or 4. In contrast to the segment PLTS application, there are several crossings on residential streets that are PLTS 2, rather than PLTS 1. This can be attributed to a lack of crosswalk markings. However, if data were available on residential traffic speeds, these streets could be reassessed. If actual traffic speeds are below 25 mph, some of these crossings may be PLTS 1. Note that the crossing PLTS data inputs were more time-consuming to collect, so we focused on a smaller portion of Shorewood.

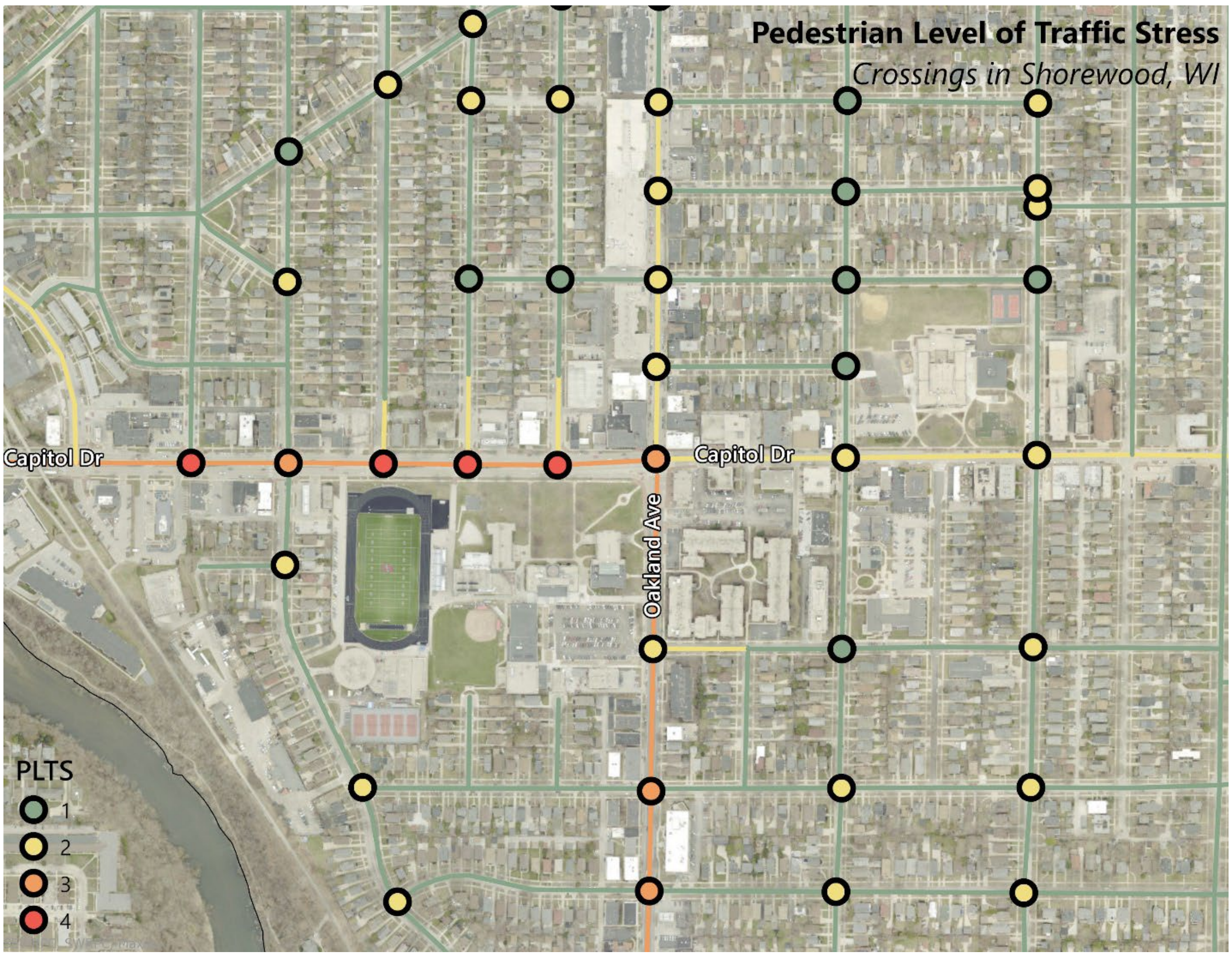


Figure 2. Crossing PLTS ratings in the southwest part of Shorewood, WI

Example 2: Corridor application to N. Van Buren Street (Milwaukee, WI)

In addition to evaluating pedestrian suitability in small areas, PLTS can also be applied to roadway corridors. Some street segments have characteristics that change fairly frequently, even block-to-block. Doing a detailed PLTS evaluation of an individual corridor can account for these fluctuations and help target specific design changes that could be made to improve pedestrian comfort.

We use N. Van Buren Street in Milwaukee, WI as our first example of a corridor-level PLTS application. This one-mile corridor in downtown Milwaukee was reconfigured in 2022 and reconstructed in 2024, providing an excellent opportunity to evaluate PLTS. Doing a detailed evaluation of an individual corridor before and after a project can help assess the impacts of specific design changes on pedestrian stress. Plus, detailed measurements of PLTS inputs were available because of the reconstruction project.

Prior to being redesigned, the corridor was four lanes with left- and right-turn lanes at various intersections. It had a 30 mph posted speed limit and 7,000 to 10,000 AADT. Its segments varied in sidewalk width, buffer width, and crossing treatment. Despite the block-to-block variance, most segments of Van Buren Street were PLTS 1, largely due to on-street parking serving as a buffer between the street and sidewalk. However, most crossings of the corridor were rated PLTS 3 or 4 (Figure 3). The crossings were more stressful because they spanned 4 or 5 lanes and lacked crossing treatments other than traffic signals.

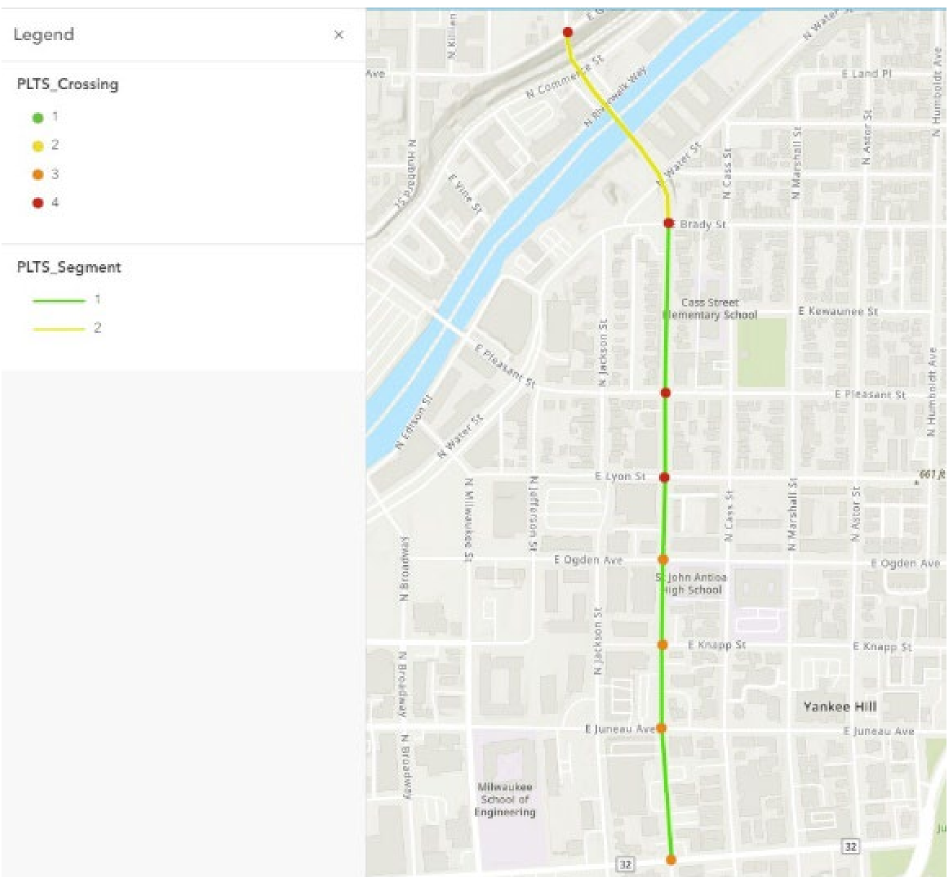


Figure 3. N. Van Buren Street Segment and Crossing PLTS ratings before redesign project

N. Van Buren Street was reconstructed with fewer general-purpose travel lanes and a two-way protected bike lane on its east side (Figure 4). Crosswalks were enhanced with curb extensions. Evaluating the PLTS shows how these transformations impacted pedestrians' experiences around traffic in the corridor. Due to the reduction in lanes and improved crossing treatments, the corridor saw a dramatic reduction in pedestrian crossing stress. Crossing PLTS dropped to PLTS 2 at all intersections (Figure 5).

Note that the PLTS changes were calculated assuming the same traffic volume and speed before and after the project. However, post-construction studies of the corridor may show slower traffic speeds, which would result in even better crossing PLTS ratings. By noting these changes, a community can use PLTS as a piece to evaluate a corridor redesign.

Source: City of Milwaukee (2024). Van Buren Street Transformation Project, https://engage.milwaukee.gov/download_file/186/546.

Figure 4. Rendering of N. Van Buren Street after redesign project

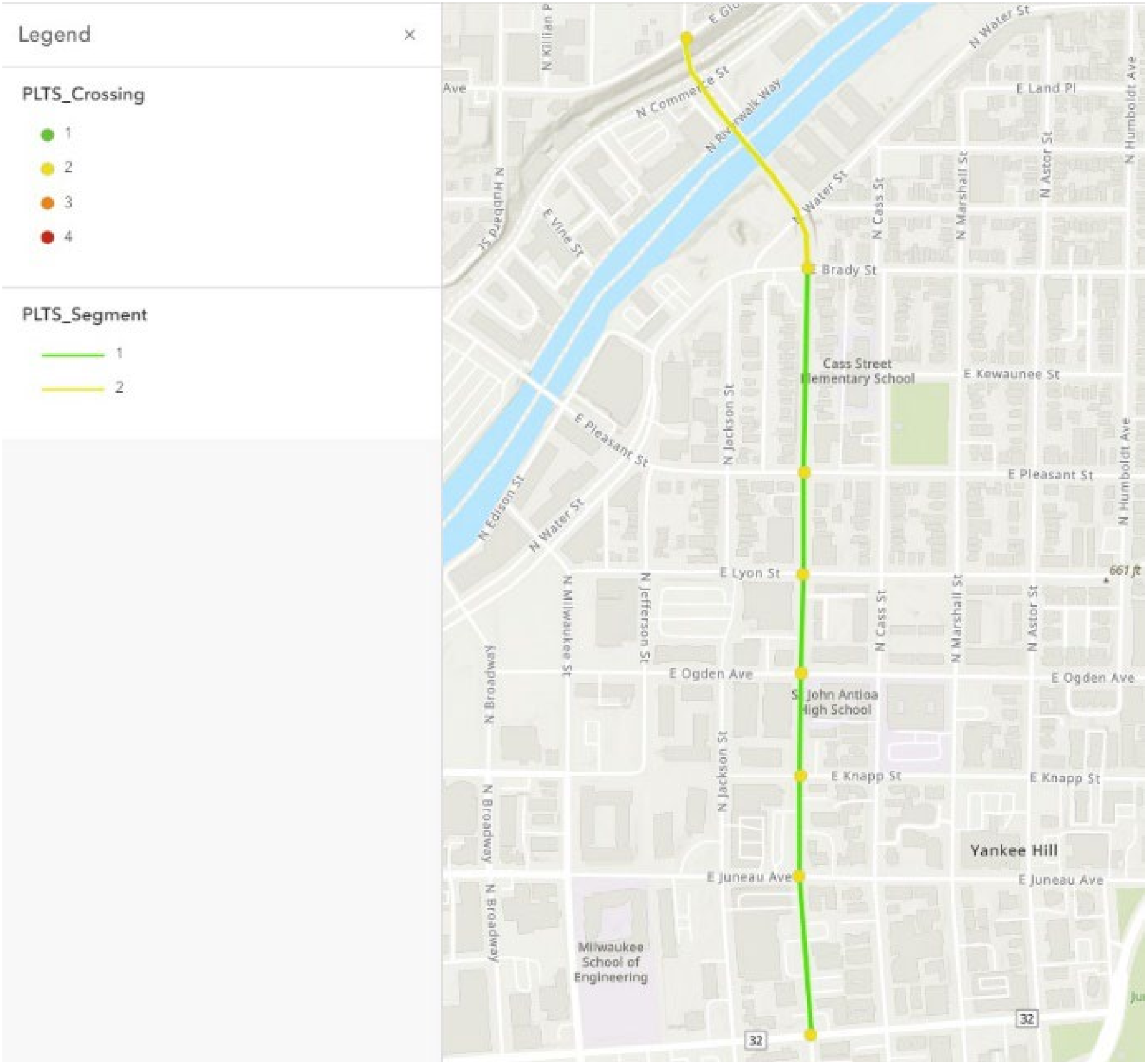
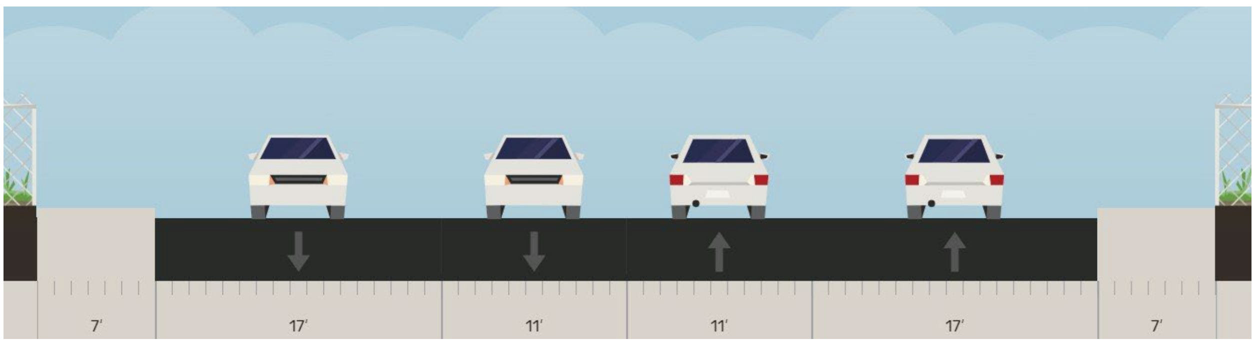


Figure 5. N. Van Buren Street Segment and Crossing PLTS ratings after redesign project

Example 3: Corridor application to N. 16th Street Viaduct (Milwaukee, WI)

Another use for the PLTS tool is to evaluate roadways that are currently unsafe or uncomfortable, and test how different redesign alternatives may impact pedestrian stress. This can help identify which changes might be the most suitable in a particular corridor.

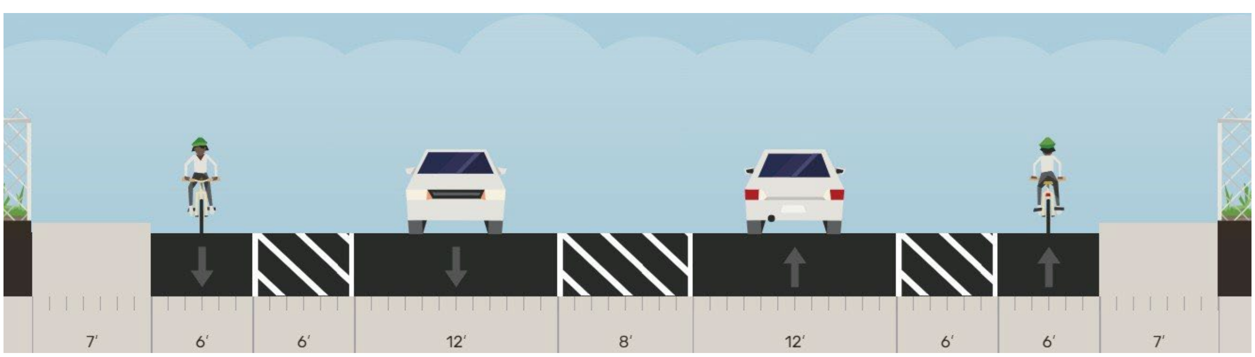
We analyzed the N. 16th Street Viaduct corridor over Milwaukee's Menomonee Valley because it has high traffic volumes (AADT) and many motor vehicles exceed the posted speed limit of 30 mph. The high speeds are likely due to the street's wide lanes and the bridge creating a long straightaway with few intersections. This corridor also has 7-foot concrete sidewalks directly adjacent to the curbside travel lane, making it an unpleasant experience for pedestrians. There are also no crossing treatments along the corridor (Figure 6). These factors result in current segment PLTS and crossing PLTS ratings of 4.



Source: Streetmix (2024). www.streetmix.net.

Figure 6. N. 16th Street Viaduct current cross-section measurements

After evaluating different roadway redesigns, even a simple paint-and-post reconfiguration from four lanes to two lanes can make a significant impact on pedestrian comfort. Within this two-lane design, adding a 6-foot bike lane and 6-foot buffer improves the prior segment PLTS rating from 4 to 2 (Figure 7). Depending on a community's goals, this can indicate that this is a good roadway redesign, or to push even further to reach a PLTS of 1. This is a functional and forward-looking use of PLTS to improve conditions for pedestrians.



Source: Streetmix (2024). www.streetmix.net.

Figure 7. Potential reconfiguration of N. 16th Street Viaduct cross-section

Example 4: Segment application to Highway G (Egg Harbor, WI)

The impact of adding a sidewalk can also be shown using PLTS. While useful for larger areas or corridor studies, PLTS can also be used for evidence of the benefits of improved facilities on a single roadway segment. One example is the addition of an eight-foot sidewalk along Highway G in Egg Harbor, WI. Prior to 2019, this area had no sidewalk or pedestrian facilities (Figure 8).

Other than constructing the new sidewalk, there were no changes to roadway traffic volume, speed, or buffer (Figure 9). This simple change improved the segment PLTS rating from 4 to 3. While a minor change, this still shows the impact of the facility on pedestrian comfort immediately. This suggests that PLTS can be used by a community to show the benefits of new pedestrian facilities, dedicated pedestrian spaces, and complete streets. PLTS can be applied after construction, or as shown by Example 3, to advocate for improvements prior to construction.

Source: Google Maps. (2024). Streetview, https://www.google.com/maps.

Figure 8. Highway G with no sidewalk in 2013

Source: Google Maps. (2024). Streetview, https://www.google.com/maps.

Figure 9. Highway G with sidewalk in 2023

Example 5: High Injury Network Safety Analysis Application (Milwaukee, WI)

Besides evaluating pedestrian comfort along corridors or throughout small areas, PLTS can be used as a tool within a broader safety analysis. In Milwaukee, a 2023 Crash Analysis Report identified a High Injury Network that contained the most dangerous streets and intersections in the city (City of Milwaukee 2023). While PLTS is a measure of perceived stress rather than a direct measure of crash risk, the two are related. PLTS ratings can provide additional context for safety analyses, particularly to highlight specific areas of a community that are high priorities for physical improvements. Table 14 lists the six most dangerous intersections for pedestrians in Milwaukee according to the Crash Analysis Report. Applying the crossing PLTS shows that each of these intersections have a rating of 3 or 4. The results are not surprising for these intersections, and they confirm a need for safety improvements. The analysis process could also identify certain intersections that have inconsistent crash risk and PLTS outcomes. This might suggest the need for additional analysis to understand the underlying reasons for this inconsistency (e.g., very stressful crossings that experience few crashes because most pedestrians avoid them). Overall, PLTS is not meant to replace crash analysis, but is a complementary tool that a community can use to target segments or corridors in need of design changes.

Table 14. Crossing PLTS at the most dangerous intersections for pedestrians in Milwaukee

Intersection Name	PLTS
N 14th St & Atkinson Ave	4
N 35th St & W Highland Blvd	3
S Cesar E Chavez Dr & W Mineral St	3
N 41st St & W North Ave	3
N 91st & W Appleton Ave	4
N 24th St & W Center St	3

Source of intersections: City of Milwaukee (2023). Milwaukee Crash Analysis Report.

Example 6: Challenges with applying PLTS to evaluate new uses of street space (Milwaukee, WI)

As communities rethink the best uses of public rights of way, roadway lanes are being used for more purposes than simply accommodating personal vehicles. Examples include protected bike lanes, dedicated bus lanes, micromobility parking, short-term delivery zones, and many more. This presents challenges when evaluating PLTS. These different applications create unique situations that are not feasible to cover within relatively simple PLTS tables. Communities are likely to ask what should be considered as a travel lane for evaluating PLTS. One example in Milwaukee, WI is W. Wisconsin Avenue, where general-purpose travel lanes were transitioned to a dedicated bus lane to accommodate a new Bus Rapid Transit line.

The roadway consists of four lanes total, two of which are bus-only lanes. There are 8- to 10-foot sidewalks along the corridor, but there is no buffer between them and the bus only lane. As this is not a fully separated lane, it highlights the challenges of determining the PLTS rating. Buses use the lane, albeit in intervals, and personal vehicles can easily, though illegally, still use the lane. Therefore, the PLTS analyst must decide whether to consider the bus-only lane a buffer or a travel lane. If the bus-only lane is counted as a traffic lane, the resulting segment PLTS is 3 and crossing PLTS varies between 3 and 4. If the bus-only lane is considered a buffer, then the PLTS reduces to a segment rating of 1 and crossing rating that varies between 2 and 3. In the PLTS Method section above, we specify that bus-only lanes should be counted as buffer space. However, if other automobiles routinely encroach on the bus lanes, they should be considered travel lanes.

There are likely to be other new or occasional lane uses that are not covered by PLTS guidance. This highlights the challenge that some PLTS evaluations may require user judgement based on local community context. These situations should be flagged for future research.

Conclusion and Future Research

This study builds off the research and development of similar pedestrian suitability evaluation methods, creating a PLTS tool that is intended to be more straightforward and easier to use than some of the previous, pioneering approaches. We hope that this version of PLTS will be useful for widespread practical application and become the basis for further iterations of a commonly-applied tool.

Still, we acknowledge that the PLTS method as a simplified representation of the pedestrian experience. Going through the process to build the PLTS tables, it became clear that distilling the pedestrian stress into a handful of tables is challenging. There are several factors that have not been included in the final tables that are still important to the pedestrian experience (e.g., sidewalk surface conditions, lighting, pedestrian volumes, noise, personal security), and further research may be necessary to determine if any of these factors should be included in future iterations of the PLTS tables. Additionally, new uses of street space, such as dedicated bus lanes, short-term parking zones, and other facilities should be studied to determine whether they should be counted as travel lanes or buffer space or be represented in some other way.

Further, different people perceive the pedestrian environment in different ways. We established the four main stress categories with children, older adults, and people with disabilities in mind. However, across the spectrum of personal traits and levels of risk tolerance, not all people's individual perceptions of stress will fit the four stress categories perfectly. Different PLTS ratings for different types of pedestrians could be explored in the future, but adding more dimensions to the method must be balanced carefully against the downside of increasing its complexity and potentially reducing its usefulness.

Future iterations of the PLTS method could also be simplified so that they only use roadway data that most agencies already have. This would make PLTS easier to apply more broadly, at the network scale. The PLTS method described in this report is intended to be applied at a project scale. It requires several data inputs that are often unavailable or time-consuming for transportation agencies to collect (e.g., buffer width, specific locations of pedestrian crossing treatments). These inputs often need to be collected in the field or from aerial and street-level images. Earlier in the document, we identified several data inputs that could be excluded from our project-scale PLTS in the future to potentially create a network-scale PLTS.

The PLTS method described in this report and other future versions of PLTS can also be improved through several other future research initiatives.

- Compare the PLTS ratings with stress levels reported by a sample of pedestrians on actual roadway segments and crossings. Survey data should be collected to validate and potentially adjust the stress levels specified in the PLTS tables. The sample of pedestrians should include parents of children, older adults, and people with disabilities.

- Test for differences in pedestrian stress levels in different parts of the US. There may be differences in how pedestrians perceive traffic stress between different metropolitan regions or between urban, suburban, and rural communities.
- Compare PLTS ratings with reported pedestrian crashes. A simple type of validation should examine how closely PLTS categories compare with pedestrian crashes or serious injuries. In theory, roadways with the highest stress levels will also have the most crashes and injuries, all else equal. However, roadways that are more stressful for pedestrians may also deter walking, so they may have lower pedestrian activity levels (i.e., unmet pedestrian demand). Therefore, researchers should try to compare PLTS ratings with pedestrian crash rates (e.g., number of reported pedestrian crashes divided by the actual number of pedestrians walking along or crossing in particular locations).
- Provide guidance to evaluate potential crossing locations within long roadway segments. Some roadway corridors have very long distances between formal pedestrian crossings. These segments lack obvious mid-block locations to evaluate crossing PLTS. Infrequent crossing opportunities, on their own, contribute to pedestrian stress in the roadway environment. Therefore, researchers should determine appropriate distance intervals to assess crossing PLTS in the middle of long roadway segments. This type of analysis could help identify roadway segments that need new, formalized mid-block pedestrian crossings.

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