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Appendix C: Level of Traffic Stress Analyses

Introduction

As part of developing an active transportation plan for the City of Santa Cruz, Toole Design performed two Level of Traffic Stress (LTS) analyses to assess current conditions for walking and bicycling. The results of the analyses will be combined with site visit observations; public input from the online map, pop-up events, and focus groups; and professional judgement to develop recommendations. The analysis results can also be used for prioritizing recommendations and developing performance measures. Table 1 describes the two analyses.

Table 1: Network Assessment Analyses

Analysis	Description
Bicycle Level of Traffic Stress (BLTS)	Assigns streets a score based on how comfortable they would be for a bicyclist who is interested in riding, but concerned about traffic safety (i.e., an "interested but concerned" bicyclist). Though designed for bicyclists, this analysis can be used to evaluate the level of stress for micromobility users (e.g., scooters, assisted mobility devices, etc.) as well.
Pedestrian Crossing Level of Traffic Stress (PxLTS)	Assigns intersections a score based on how comfortable they would be for pedestrians crossing the street.

Bicycle Level of Traffic Stress (BLTS) Analysis

The BLTS analysis estimates the amount of stress a person bicycling experiences due to roadway and traffic conditions on a given street segment. The methodology was first proposed by Furth, Mekuria, and Nixon in 2012,[1] and has since been periodically updated and refined by researchers. LTS values range from 1 to 4, with LTS 1 representing the lowest stress and LTS 4 representing the highest stress, as shown in Figure 1. LTS 1 and LTS 2 are generally considered low stress, which is acceptable to most of the adult population. A segment's LTS value depends on factors

[1] https://transweb.sjsu.edu/research/Low-Stress-Bicycling-and-Network-Connectivity

such as number of travel lanes, traffic volumes, posted speeds, presence, type, and width of bicycle facilities, and presence of parking lanes. Table 2 lists the data inputs, sources, and any assumptions used to fill in data gaps for the Santa Cruz BLTS analysis.

Figure 1: Visual Representation of Bicycle Level of Traffic Stress

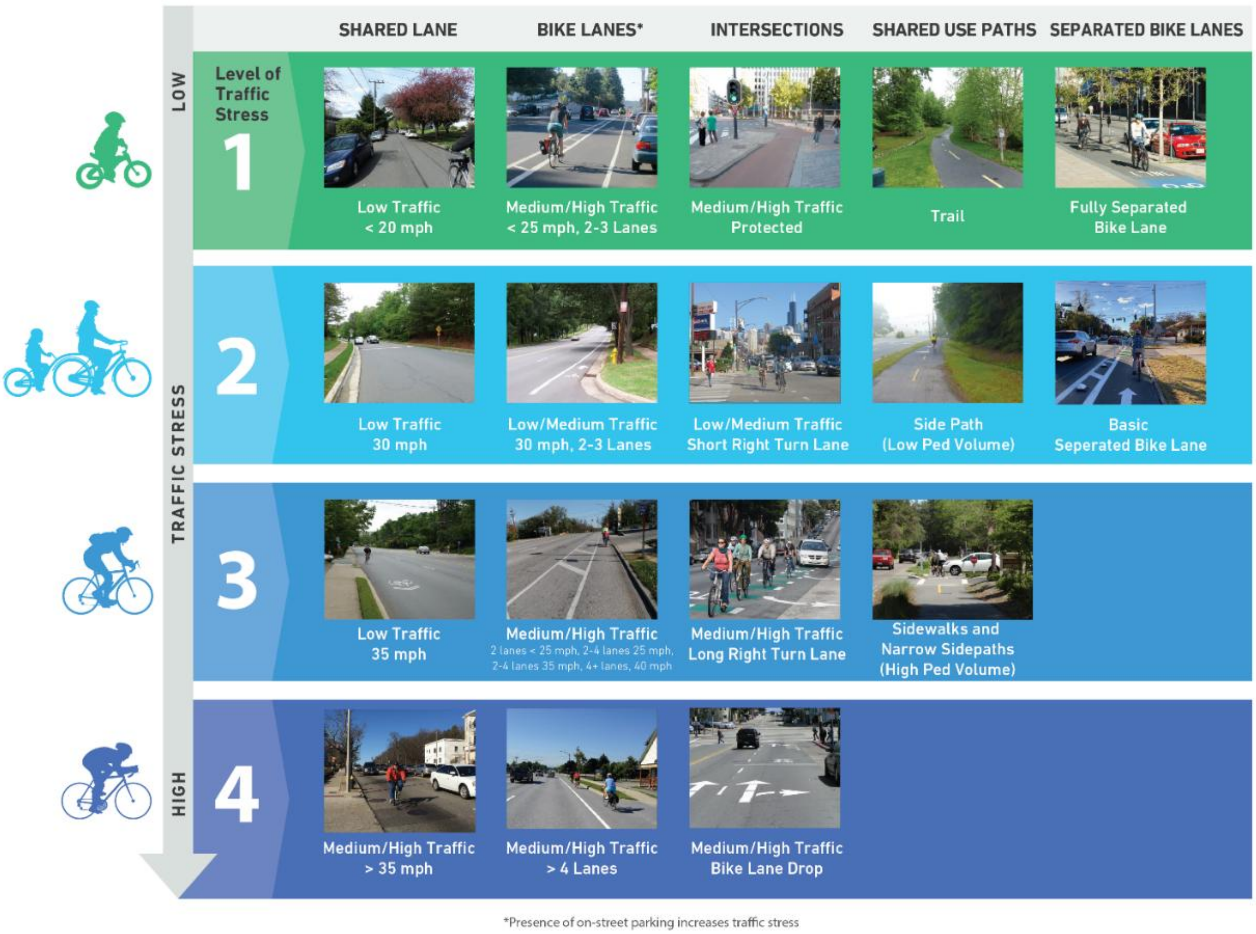


Table 2: Data Inputs for Bicycle LTS

Input	Data Source	Assumptions for Data Gaps
Functional classification	City-provided	N/A
Number of travel lanes	No city data available	1. Checked Open Street Map for lane data 2. Any remaining data gaps were filled via desktop review in Google Maps/Earth
Traffic volumes (AADT)	Replica, 2024	For any NULL values, we looked at data on similar or adjacent streets
Posted Speed	City-provided	N/A
One-way information	No city data available	Open Street Map
Marked centerline information (dual carriageway)	No city data available	Assumed based on functional classification
Existing and proposed bicycle facilities	City-provided; updated by the project team to include facilities implemented since last update	N/A
Width of existing bicycle facilities	City-provided	Desktop review in Google Maps/Earth
Parking presence (and lane width if next to a bicycle lane)	No city data available	Desktop review in Google Maps/Earth

LTS Criteria

Using the LTS criteria, all street segments on which bicycles are allowed are assigned a stress level. Alleyways, off-street paths, and places where bicycles are prohibited were excluded from the analysis.

The following tables illustrate how the LTS scores are calculated based on average daily traffic (ADT), posted speed limit, number of lanes, presence of a marked centerline, and the type of on-street bicycle facilities. Separated bicycle lanes and off-street shared-use paths receive an LTS score of 1 (lowest stress) by default.

Table 3: Criteria for mixed traffic (i.e., no bicycle lane or other dedicated bicycle facility)

Number of lanes	Effective ADT*	Prevailing Speed						
		≤ 20 mph	25 mph	30 mph	35 mph	40 mph	45 mph	50+mph
Unmarked 2-way street (no centerline)	0-750	LTS 1	LTS 1	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3
	751-1500	LTS 1	LTS 1	LTS 2	LTS 3	LTS 3	LTS 4	LTS 4
	1501-3000	LTS 2	LTS 2	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4
	3000+	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
1 thru lane per direction (1-way, 1-lane street or 2-way street with centerline)	0-750	LTS 1	LTS 1	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3
	751-1500	LTS 2	LTS 2	LTS 2	LTS 3	LTS 3	LTS 4	LTS 4
	1501-3000	LTS 2	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4
	3001-6000	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
	6001-10,000	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
	10,001+	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
2 thru lanes per direction	0-6000	LTS 3	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4
	6001-12,000	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
	12,001+	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
3+ thru lanes per direction	any ADT	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4

* Effective ADT = ADT for two-way roads; Effective ADT = 1.67*ADT for one-way roads

Table 4: Criteria for bicycle lanes not adjacent to a parking lane

Number of lanes	Bicycle lane width	Prevailing Speed					
		≤ 25 mph	30 mph	35 mph	40 mph	45 mph	50+ mph
1 thru lane per direction, or unmarked	6+ ft	LTS 1	LTS 1	LTS 2	LTS 3	LTS 3	LTS 4
	4 or 5 ft	LTS 2	LTS 2	LTS 3	LTS 3	LTS 3	LTS 4
2 thru lanes per direction	6+ ft	LTS 2	LTS 2	LTS 3	LTS 4	LTS 4	LTS 4
	4 or 5 ft	LTS 2	LTS 2	LTS 3	LTS 4	LTS 4	LTS 4
3+ lanes per direction	any width	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4

Notes:

1. If bicycle lane / shoulder is frequently blocked, use mixed traffic criteria.
2. Qualifying bicycle lane / shoulder should extend at least 4 ft from a curb and at least 3.5 ft from a pavement edge or discontinuous gutter pan seam.
3. Bicycle lane width includes any marked buffer next to the bicycle lane.

Table 5: Criteria for bicycle lanes next to a parking lane

Number of lanes	Bicycle lane reach = Bicycle + Parking Lane width	Prevailing Speed				
		≤ 20 mph	25 mph	30 mph	35 mph	40+ mph
1 lane per direction	15+ ft	LTS 1	LTS 1	LTS 2	LTS 3	LTS 4
	14 ft	LTS 2	LTS 2	LTS 3	LTS 3	LTS 4
	12-13 ft	LTS 2	LTS 3	LTS 3	LTS 3	LTS 4
2 lanes per direction (2-way) 2-3 lanes per direction (1-way)	15+ ft	LTS 2	LTS 2	LTS 3	LTS 3	LTS 4
	14 ft	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4
	12-13 ft	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4
Other multilane		LTS 3	LTS 3	LTS 3	LTS 4	LTS 4

Notes:

1. If bicycle lanes are frequently blocked, use mixed traffic criteria.
2. Qualifying bicycle lane must have reach (bicycle lane width + parking lane width) > 12 ft.
3. Bicycle lane width includes any marked buffer next to the bicycle lane.

Results

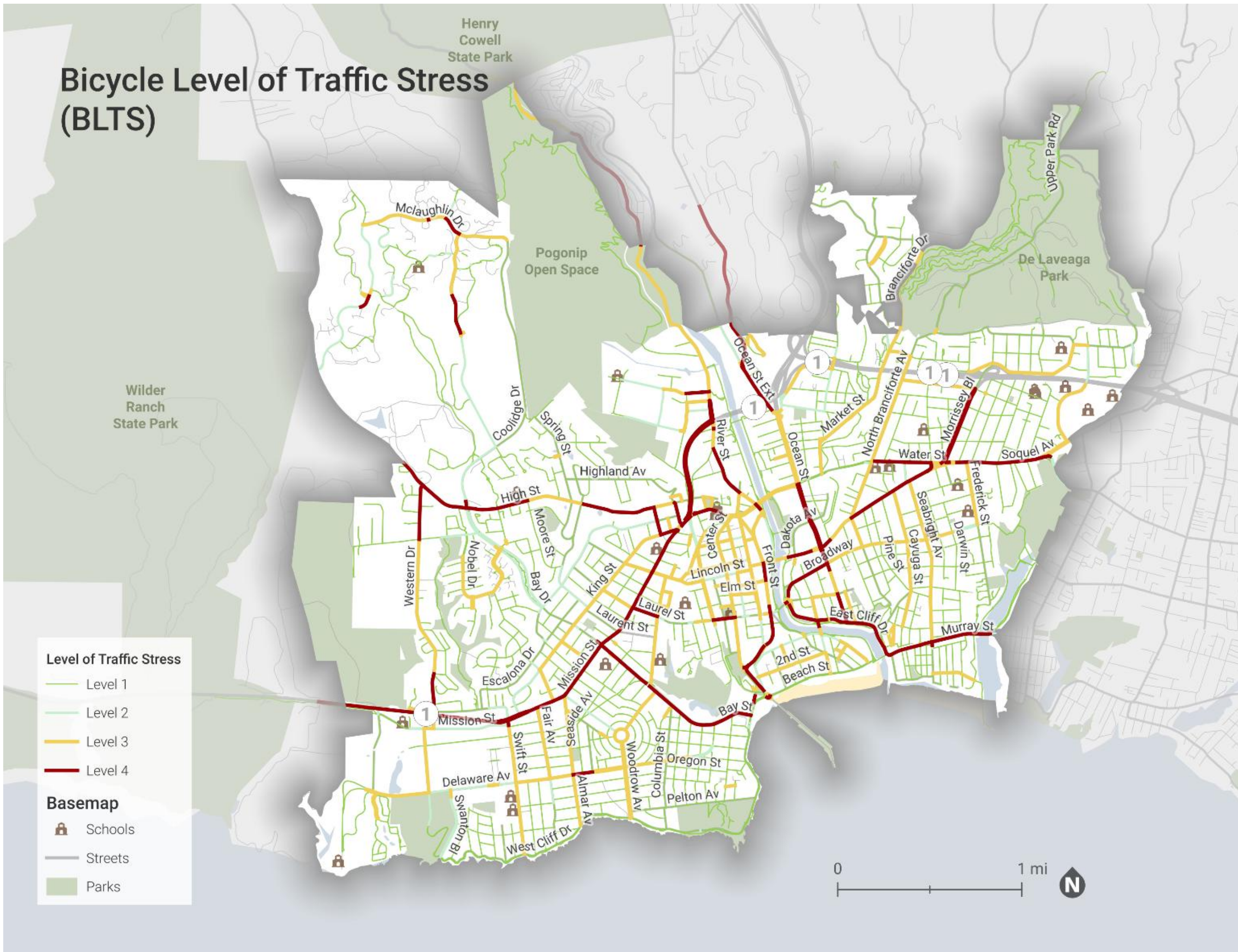
Table 6 summarizes the total centerline miles for each BLTS level and Figure 2 is a map showing the BLTS level for streets in Santa Cruz. Most local streets, or around 72% of the city's roadway network, are assigned Level 1 or 2 and would be comfortable for most adults to bicycle on. The remaining 28% of the roadway network, mostly collectors and arterials, are assigned Level 3 or 4, indicating they are highly stressful to bicycle on. These streets include most arterials and collectors in Santa Cruz, as well as most of downtown.

As in many other cities, the arterials and collectors in Santa Cruz offer some of the only continuous routes and are where many destinations are located. These are also some of most difficult locations to install fully separated bicycle facilities due to high traffic volumes, transit routes, and constrained right-of-way.

Table 6: Segment-level Level of Traffic Stress Summary

Level of Traffic Stress	Total Length (miles)	Percentage of Total Length
LTS 1	112	63%
LTS 2	15	9%
LTS 3	34	19%
LTS 4	16	9%

Figure 2: BLTS Map



Notes:

1. The analysis calculates a BLTS score for each direction of travel, but for legibility, Figure 2 shows the highest stress BLTS score on each segment.
2. Different BLTS levels along a corridor may be caused by:
    a. The addition of turn lanes near intersections
    b. Increases or decreases in traffic volumes
    c. Bicycle facility changes along the corridor
    d. The presence of on-street parking in some places along the corridor but not in others
3. Higher BLTS levels (3 or 4) along corridors with existing bicycle facilities are likely caused by insufficient widths when combining the widths of the bicycle facility with the adjacent parking lane.
    a. For Santa Cruz, width data was collected manually via aerial imagery, limiting accuracy.
    b. Physical constraints often require minimum widths be used to implement bicycle facilities, prioritizing overall network connectivity over traffic stress on a given segment.

Pedestrian Crossing Level of Traffic Stress (PxLTS) Analysis

PxLTS assigns pedestrian crossings a score based on how comfortable they would be for pedestrians crossing the street. The analysis considers traffic volumes, posted speeds, number of lanes being crossed, the lane count of the adjacent street, and if a traffic control device, median refuge, or crossing island is present. Higher speeds, volumes, and the number of lanes being crossed all correlate to higher pedestrian stress levels.

The methodology presented below is modified from the framework developed by the Oregon Department of Transportation (ODOT).[2] The ODOT methodology and our approach differ depending on the type of traffic control device at the intersection. Our approach assigns different scores to unsignalized intersections versus signal-controlled intersections.

Each crossing is assigned a PxLTS score from 1 to 4, which are described in Table 7. ODOT's procedures manual identifies PxLTS 2 as a reasonable target for most situations. PxLTS 2 conditions are considered appropriate for most adults. Note that this analysis does not include an assessment of accessibility for people with disabilities, such as lack of ADA-compliant curb ramps, poor pavement in the crossing, and other factors impacting accessibility.

Table 7: PxLTS Descriptions

Level	Description
PxLTS 1	Represents little to no traffic stress for people of all ages.
PxLTS 2	Represents little traffic stress for most adults but requires more attention and understanding of traffic than children ages 10 and younger may be capable of.[3]
PxLTS 3	Represents moderate stress; a higher level of attention to traffic is needed, and adults may feel some discomfort using this facility.
PxLTS 4	Represents high traffic stress. Only pedestrians with limited route choices would use this facility.

[2] Oregon Department of Transportation. (02/2025). Analysis Procedures Manual Chapter 14. https://www.oregon.gov/odot/Planning/Documents/APMv2_Ch14.pdf

[3] "Child Pedestrian Safety Education: Applying Learning and Developmental Theories to Develop Safe Street-Crossing Behaviors," 2009, https://doi.org/10.21949/1525673

Data Inputs and Approach

Table 8 lists the data inputs for the PxLTS assessment for Santa Cruz. Given the limitations of existing spatial data for the PxLTS analysis, the project team focused on analyzing a subset of intersections along collector and arterial streets. For this analysis, collector and arterial streets are defined as having two or more lanes, speed limits above 30 mph, or AADT over 7,000. These streets are labeled on the map in 3 as "Focus Roadways." The project team used aerial imagery and Street View in Google Maps to review 214 intersections along these streets.

Table 8: Data Inputs for Pedestrian Crossing LTS

Input	Data Source	Assumptions for Data Gaps
Number of through lanes	No City data available	1. Checked Open Street Map for lane data 2. Any remaining data gaps were filled via desktop review in Google Maps/Earth
Traffic volumes (AADT)	Replica	For any NULL values, we looked at data on similar or adjacent streets
Posted Speed	City-Provided	N/A
Median refuge/crossing island presence/absence	No City data available	Desktop review in Google Maps
Traffic signals	RRFB, Signal Poles data received from City	Desktop review in Google Maps

LTS Criteria

Tables 9 and 10 summarize how the PxLTS scores are calculated. For the purposes of this analysis, crossings with pedestrian hybrid beacons (PHBs) are considered **signalized** crossings. Locations with RRFBs, stop-controlled intersections, and uncontrolled crossings are considered **unsignalized.**

Unsignalized Crossings

The methodology for unsignalized crossings follows the original ODOT methodology, using the same inputs of lane count, speed, and crossing island presence. Functional classification is not considered because it is important to assess the roadway as it actually operates. For example, if there is a collector road with speeds and volumes more in line with a typical arterial road, it makes sense that the crossings should receive the same scores as the crossings on an arterial with the same characteristics.

Table 9: Criteria for Unsignalized Crossings

Lanes Crossed*	AADT	Island	Posted Speed Limit			
			≦ 25 mph	30 mph	35 mph	40+ mph
1	Any	No	1	1	2	3
		Yes	1	2	2	3
2	0-1000	No	1	2	2	3
	1001-5000		1	2	3	3
	5001-9000		2	3	3	4
	9001 +		3	3	4	4
	0-5000	Yes	1	2	2	3
	5001-9000		2	2	2	3
	9001 +		2	2	3	4
3	0-1000	No	2	2	3	4
	1001-8000		3	3	4	4
	8001-12000		3	3	4	4
	12001 +		4	4	4	4
	0-1000	Yes	1	1	2	3
	1001-8000		2	2	3	4
	8001-12000		2	3	4	4
	12001 +		3	3	4	4
4+	Any	Any	4	4	4	4

*Total number of lanes in both directions, including turning lanes, but not on-street parking lanes.

Signalized Crossings

Our methodology for signalized crossings differs significantly from the original ODOT methodology (which assumes all signalized crossings are PxLTS 1 or 2 with a few exceptions) and is based on the project team's professional judgment and experience regarding what makes a signalized intersection high or low stress. Notably, this methodology includes more nuance regarding the influence of the number of lanes, left turn conflicts, and various traffic control treatments.

Because cross traffic is stopped by the signal, speed, and volume of traffic on the street being crossed has a different degree of influence on comfort and safety. Instead, roadway width and interactions with turning traffic are the primary factors for safety and comfort at signalized intersections. Various other factors influence the comfort and safety of a signalized intersection (including presence of turn lanes on the street being crossed and on the intersecting street, whether right-turn-on-red is allowed, whether left turn signals are "permissive" or "protected," and the speed and volume of turning traffic from the intersecting street). Where data is available, these factors may be used to adjust the score at a signalized intersection. However, with no data regarding the presence of these factors, they were not considered for this initial PxLTS analysis.

Table 10: Criteria for Signalized Crossings

Configuration of the intersecting ("walking along") street*	**Total Lanes Crossed***				
	2 Lanes	3 Lanes	4 lanes	5 lanes	6+ Lanes
PHB at midblock locations	1	2	3	3	3
2 Lanes	2	2	3	3	4
3 Lanes	2	3	3	4	4
4 Lanes	2	3	3	4	4
5 Lanes	3	3	4	4	4
6+ Lanes	3	4	4	4	4

*Total number of lanes in both directions, including turning lanes.

Results

Table 11 summarizes the PxLTS scores for all the study intersections, as well as for the subset of study intersections within a ¼ mile of a city school.

Over 82% of intersections along focus roadways and 76% of analyzed intersections within a ¼ mile of schools are high stress (PxLTS 3 or 4), indicating the larger roadways in Santa Cruz are often barriers for people walking and bicycling. Further study of these locations will inform intersection recommendations in the Active Transportation Plan Update. Potential strategies to reduce PxLTS include lowering speed limits, adding pedestrian crossing islands, implementing turn restrictions, and adjustments to signal phasing. Additionally, the project team can explore adding adjustment factors to the scoring criteria for signalized intersections (to lower the PxLTS) and calculating the distance between lower stress intersections on the focus roadways (to locations for priority crossing improvements).

Table 11: Level of Pedestrian Crossing Level of Traffic Stress Summary

Intersection Location	Total Analyzed Intersections	PxLTS 1	PxLTS 2	PxLTS 3	PxLTS 4
All Focus Roadways	214	9	31	100	74
	100%	4%	14%	47%	35%
Within ¼ mile of schools	97	3	20	37	37
	100%	3%	21%	38%	38%

Figure 3: PxLTS Map