Appendix 4: Level of Traffic Stress (LTS) Analysis Methodology Memorandum

Fort Worth Active Transportation Plan

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North Central Texas Council of Governments

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MEMORANDUM

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North Central Texas Council of Governments: Kevin Kokes, AICP and Daniel Snyder

From: Toole Design: Darren Flusche, Project Manager, and Spencer Gardner, AICP, Senior Data Analyst

Project: Fort Worth Active Transportation Plan

Re: Bicycle Level of Traffic Stress Methodology

This memorandum explains the methodology used to calculate Bicycle Level of Traffic Stress for the City of Fort Worth and its extraterritorial jurisdiction as part of the Fort Worth Active Transportation Plan. The results of this analysis are available online at http://fortworthtexas.gov/atp/. This memo is comprised of five major sections:

Background (page 1) details the origins of the Level of Traffic Stress approach.

Segment LTS Methodology (page 3) describes the analysis criteria and approach to scoring segments.

Intersection LTS Methodology (page 5) presents the analysis criteria and approach to scoring intersections.

Data (page 6) summarizes input data, their sources, and analysis assumptions.

Lim**itations** (page 8) explains the data and methodological limitations and offers recommendations for improving future analyses.

Background

The Bicycle Level of Traffic Stress (LTS) methodology was developed in 2012 and first published in a report by the Mineta Transportation Institute.[1] LTS uses readily available roadway data to help planners understand how comfortable a roadway may be for bicycling. LTS scores range from LTS 1 (low-stress) to LTS 4 (high-stress), described in Table 1. The Mineta LTS is a “worst case scenario” analysis whereby the score for the street segment is dictated by the highest/worst score received by any one characteristic of that street (number of lanes,

[1] Mekuria, Maaza C., Peter G. Furth, and Hilary Nixon. "Low-stress bicycling and network connectivity." (2012).

speed, bike lane presence/width, parking presence). For instance, a low-volume, two-lane street with a speed limit of 40 mph would rate poorly with an LTS 4 score because of the high speed limit.

Level of Traffic Stress also assesses the impact of intersections on bicyclist stress. The original Mineta LTS paper presented a complex assessment of intersection and intersection approach stress involving the configuration of bike lanes, through lanes, and right-turn lanes; right-turn lane width; traffic control; and characteristics of the street being crossed. In more recent work, including most projects Toole Design has worked on, the LTS stress score for crossings has been limited to the speed and number of lanes of the crossing street, as well as the presence of a traffic signal. This is due to the relative scarcity of good data on many of the additional characteristics used in the original Mineta report.[2] In the City of Fort Worth LTS analysis, the intersection score is represented on the street segment approach leg. Intersection analysis is critical to understanding high-stress barriers between existing low-stress streets.

The LTS analysis for the City of Fort Worth used the Mineta LTS methodology with refinements that have been developed in the last few years.[3]

Table 1. Level of Traffic Stress Score Descriptions

LTS	Target Bicycle User Type	Description
1	All Ages and Abilities	Presenting little traffic stress and demanding little attention from bicyclists, and attractive enough for a relaxing bike ride. Suitable for almost all bicyclists, including children trained to safely cross intersections. On links, bicyclists are either physically separated from traffic, are in an exclusive bicycling zone next to a slow traffic stream with no more than one lane per direction, or are on a shared road where they only occasionally interact with motor vehicles (as opposed to a stream of traffic) with a low speed differential. Where bicyclists ride alongside a parking lane, they have ample operating space outside the zone into which car doors are opened. Intersections are easy to approach and cross.
2	Interested but Concerned (Mainstream Adults)	Presenting little traffic stress and therefore suitable to most adult bicyclists but demanding more attention than might be expected from children. On links, bicyclists are either physically separated from traffic, are in an exclusive bicycling zone next to a well-confined traffic stream with adequate clearance from a parking lane, or are on a shared road where they only occasionally interact with motor vehicles (as opposed to a stream of traffic) with a low speed differential. Where a bike lane lies between a through lane and a right turn lane, it is configured to give bicyclists unambiguous priority where motorists cross the bike lane and to keep vehicle speed in the right-turn lane comparable to bicycling speeds. Crossings are not difficult for most adults.

[2] Lowry, Michael B., Peter Furth, and Tracy Hadden-Loh. "Prioritizing new bicycle facilities to improve low-stress network connectivity." Transportation Research Part A: Policy and Practice 86 (2016): 124-140.

[3] Furth, Peter. “Level of Traffic Stress Criteria for Road Segments, Version 2.0, June, 2017.” http://www.northeastern.edu/peter.furth/wp-content/uploads/2014/05/LTS-Tables-v2-June-1.pdf

3	Enthused and Confident (Adult Commuters)	More traffic stress than LTS 2, yet markedly less than the stress of integrating with multilane traffic, and therefore welcome to many people currently riding bikes in American cities. Offering bicyclists either an exclusive riding zone (lane) next to moderate-speed traffic or shared lanes on streets that are not multilane and have moderately low speed. Crossings may be longer or across higher-speed roads than allowed by LTS 2, but are still considered acceptably safe to most adult pedestrians.
4	Strong and Fearless (Long-Distance Recreational Bicyclists)	A level of stress beyond LTS 3, featuring streets and facilities on which few adults would feel is acceptable to bicycle.

Segment LTS Methodology

Table 2, Table 5 presents LTS criteria for separated bike lanes, based on engineering judgement and typical practices applied around the U.S. by Toole Design Group. LTS scores for separated bike lanes are based on separation type, number of adjacent travel lanes, and the posted speed limit. Trails and shared use paths are assumed to be LTS because of their complete separation from motor vehicle traffic.

Table 3, and Table 4 present refined LTS criteria from an update published on the academic webpage[4] of Peter Furth, the original creator of LTS. Improving upon the Mineta LTS criteria, the updated tables include the impact of traffic volumes in rating stress for shared lane conditions. In contrast, the original Mineta LTS methodology does not include traffic volume and substituted number of travel lanes as a proxy. While collector streets often have one lane in each direction, they can vary widely in traffic volume, width, and comfort for bicyclists, which can result in LTS scores that are a poor reflection of reality.

Table 2. LTS Criteria for Shared Lane Conditions

Mixed traffic criteria

Number of lanes	Effective ADT*	Prevailing Speed ≤ 20 mph	25 mph	30 mph	35 mph	40 mph	45 mph	50+mph
Unlaned 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 2	LTS 3	LTS 4	LTS 4	LTS 4
	3000+	LTS 2	LTS 3	LTS 3	LTS 3	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+	LTS 2	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4
2 thru lanes per direction	0-8000	LTS 3	LTS 3	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4
	8001+	LTS 3	LTS 3	LTS 4	LTS 4	LTS 4	LTS 4	LTS 4
3+ thru lanes per direction	any ADT	LTS 3	LTS 3	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

[4] Ibid.

Conventional bike lanes between a parking lane and general travel lanes are considered higher stress facilities when other variables (speed and number of lanes) are held constant. Increased traffic stress adjacent to parked cars can be caused by the potential for vehicle doors to be opened into the bicyclist's path of travel, forcing the rider into adjacent auto traffic. In addition, vehicles may cross the bike lane to park or enter into traffic. For instance, a bike lane on a 35-mph, two-lane street is scored LTS 2 if it is not adjacent to parking, regardless of width. Where the lane is adjacent to parking, it is scored LTS 3.

Table 5 presents LTS criteria for separated bike lanes, based on engineering judgement and typical practices applied around the U.S. by Toole Design Group. LTS scores for separated bike lanes are based on separation type, number of adjacent travel lanes, and the posted speed limit. Trails and shared use paths are assumed to be LTS because of their complete separation from motor vehicle traffic.

Table 3. LTS Criteria for Bike Lanes Not Adjacent to a Parking Lane

Bike lanes and shoulders not adjacent to a parking lane

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

Table 4. LTS Criteria for Bike Lanes alongside a Parking Lane

Bike lanes alongside a parking lane

		Prevailing Speed		
Number of lanes	Bike lane reach = Bike + Pkg lane width	≤ 25 mph	30 mph	35 mph
1 lane per direction	15+ ft	LTS 1	LTS 2	LTS 3
	12-14 ft	LTS 2	LTS 2	LTS 3
2 lanes per direction (2- 2-3 lanes per direction (1-way)	15+ ft	LTS 2 LTS 2	LTS 3 LTS 3	LTS 3 LTS 3
other multilane		LTS 3	LTS 3	LTS 3

Table 5. LTS Criteria for Separated Bike Lanes

Separated Bike Lane Stress					
		Prevailing Speed			
Separation Mechanism	Number of Lanes	≤ 25 mph	30 mph	35 mph	40+ mph
Substantial (Curbs, Parking, Sidewalk-level lane)	1-3 lanes	LTS 1	LTS 1	LTS 1	LTS 2
	4 lanes	LTS 1	LTS 1	LTS 1	LTS 3
	5+ lanes	LTS 1	LTS 1	LTS 1	LTS 3
Limited (Flexposts, Botts Dots)	1-3 lanes	LTS 1	LTS 1	LTS 2	LTS 3
	4 lanes	LTS 1	LTS 1	LTS 2	LTS 3
	5+ lanes	LTS 1	LTS 2	LTS 2	LTS 3

Intersection LTS Methodology

The assessment of intersections is critical to using LTS as a network tool because bicyclists are often discouraged or prevented from taking a route by the presence of a high-stress crossing. While travel along low-stress segments may be comfortable, the crossing of a major arterial without a signal can be a major barrier to bicycling. Standard traffic signals reduce, but do not wholly mitigate, the stressful impact of crossing wide, high-speed streets. A dedicated bicycle signal phase can further mitigate some of the stress, and safety countermeasures such as bicycle detection and bike boxes can also improve comfort in less direct ways.

The City of Fort Worth LTS analysis used intersection control data (full signals, RRFBs, HAWKs, four-way stops, etc.) to establish an understanding of intersection crossing comfort. Rectangular rapid flashing beacons (RRFBs) comprise a signage and pedestrian-actuated beacon treatment that improves driver yielding behavior at otherwise unsignalized crossings. Motorists are not required to stop for a flashing RRFB, but studies have shown yield compliance can increase upon installation to more than 80 percent.[5]

High-intensity activated crosswalk beacons (HAWKs) are a traffic control signal that brings cross-traffic to a stop at a marked crosswalk. When activated by push button, a HAWK begins to flash a blinking red light. When the light becomes a solid red, motorists are required to stop for crossing pedestrians. If there are no pedestrians, motorists can proceed after stopping. HAWKs have been shown to increase yield compliance to 97 percent.[6]

Table 7 presents the relationship between various intersection characteristics and traffic stress, including speed, number of lanes, and intersection controls. The intersection LTS score is symbolized on the intersection approach leg. Functional priority implies that bicyclists traveling on a thoroughfare are not subjected to stress from cross-street traffic, because cross-street traffic must yield to traffic on the thoroughfare.

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5 R. P. Godavarthy, Effectiveness of a Pedestrian Hybrid Beacon at Mid-block Crossings in Decreasing Unnecessary Delay to Drivers and Comparison to Other Systems, 2007.

6 Branyon, George. DC Experience with HAWK-Hybrid Pedestrian Signal and RRFBs, 2017.

Table 6. LTS Criteria for Crossings

Crossing Stress					
Intersection control	Number of lanes to cross	Prevailing Speed			
		≤ 25 mph	30 mph	35 mph	40+ mph
Minor Approach Stop Signs/Uncontrolled	1-3 lanes	LTS 1	LTS 1	LTS 2	LTS 3
	4 lanes	LTS 2	LTS 2	LTS 3	LTS 4
	5+ lanes	LTS 2	LTS 3	LTS 4	LTS 4
RRFB	1-3 lanes	LTS 1	LTS 1	LTS 2	LTS 3
	4 lanes	LTS 2	LTS 2	LTS 2	LTS 3
	5+ lanes	LTS 2	LTS 3	LTS 4	LTS 4
Signal / HAWK / Functional priority	1-3 lanes	LTS 1	LTS 1	LTS 1	LTS 1
	4-5 lanes	LTS 2	LTS 2	LTS 2	LTS 2
	6+ lanes	LTS 3	LTS 3	LTS 3	LTS 3
Dedicated Bicycle Signal Phase	1-3 lanes	LTS 1	LTS 1	LTS 1	LTS 1
	4-5 lanes	LTS 2	LTS 2	LTS 2	LTS 2
	6+ lanes	LTS 2	LTS 2	LTS 2	LTS 2

Data Inputs

Sources

Data was compiled from various sources into the same centerline to complete the LTS analysis. The OpenStreetMap centerline was used as the centerline to which all other jurisdictional data were joined. Where jurisdictional data were available, they were used to calculate LTS.

Table 7. LTS Input Data Sources

LTS Factor	Source	Year Updated
Speed Limit	City correspondence	2018
Number of Travel Lanes	PMA_Streets	2017
On-Street Parking Presence/Width	Street_Parking	2017
Bike Facility Presence/Width	SDE_Bike_Route	2018
Traffic Signals	Traffic_Signals	2017
Traffic Counts	TxDOT_Roadway_Inventory	2015

Assumptions

Where data was not readily available, the LTS analysis used assumptions as described in the following sections.

Posted Speed Limits

The minimum posted speed limit in Texas is 30 mph. Using this speed limit as the minimum would mean that no streets, even small residential streets, would score LTS 1 without dedicated bicycle infrastructure. This would have the effect of making bicycling on Fort Worth streets seem more stressful than it may be. To remedy this, local residential and collector streets were differentiated using a City-provided collector street layer. The collectors were scored with assumed posted speed limits of 30 mph minimum, but the local streets were scored assuming a 25-mph speed limit, allowing local streets to score LTS 1.

Centerline Presence

In the LTS methodology, the presence of a centerline is a comfort differentiator on two-lane roads. Given the same traffic speed and volume, a road with a centerline will be higher stress than one without because motorists have more room to safely and comfortably pass a bicyclist without having to cross a double-yellow line. Given that data on centerline presence was not available, functional class was used as an indicator of centerlines. Anything designated a collector or higher was assumed to have a centerline.

Traffic Volumes

Traffic volume data were only available on a limited set of roads in the overall network. Counts tend to be focused on major arterials and some collectors, so lower-volume local streets are especially unlikely to have count data. The analysis assumed that any roads classified as local carried 300 vehicles per day (vpd). This was sufficiently low to ensure LTS scoring was not negatively impacted by traffic volumes on these roads.

For all other roads, the analysis used the median count for each functional class as an assumed volume for locations where no count data was available. The following table summarizes these assumptions:

Table 8. Daily Traffic Volume Assumptions by Road Classification

Class	Daily Traffic Volume Assumption (vpd)
Local	300
Collector	3,768
Arterial	12,694

Parking

The City's parking data did not have complete parking lane width information. In locations where data was incomplete, the analysis assumed 8-foot parking lanes based on typical conditions in Fort Worth.

Limitations

Data Limitations

Given the assumptions described above, actual segment and intersection conditions may result in a segment's stress level deviating from its calculated Level of Traffic Stress. Complete data were unavailable for several variables:

1. Motor vehicle traffic counts were only available from the Texas Department of Transportation (TxDOT) and do not cover all street segments. Level of Traffic Stress classifications were generated for the segments where counts were missing, but the classifications would be more accurate with more complete traffic count data.
2. Presence of a street centerline was not available for this analysis, so the Project Team used functional class as a proxy. This may have led to the misclassification of street segments.
3. Parking lane widths were unavailable for some street segments. The width of the parking lane affects the score for segments with adjacent bike lanes. If the assumed width of 8 feet is wider or narrowed than the actual parking lane width, a segment's LTS score may not reflect real-world conditions.

Methodological Limitations

The methodology, initially published in 2012, has been improved in recent years, but still lacks some of the nuance the City of Fort Worth is interested in at both the segment- and intersection-level, particularly when it comes to signalized intersection crossings and the LTS of separated bike lanes. This analysis goes beyond currently published approaches to provide a finer-grained analysis of different separated bike lane configurations and more detailed intersection LTS ratings (Table 5 and Table 6, respectively). Without these adaptations, the City would have been unable to identify locations where stress could be reduced through best practice countermeasures. The Active Transportation Design Toolbox and Bicycle Facility Selection Guide provides information on infrastructure improvements.

Improving the LTS Dataset Moving Forward

To improve the quality of the LTS analysis in the future, the City should document and update input data as streets are built or reconstructed, speed limits are changed, and signals and safety countermeasures are installed.

Additionally, the City should consider collecting additional data related to centerline presence, traffic counts, and parking widths to replace some of the assumptions included in this analysis. This data can be collected incrementally to improve analysis quality over time.

Reference Information

Included here as a reference, the following pages present the original Mineta LTS Methodology tables.

Table 8: Criteria for Bike Lanes Alongside a Parking Lane

	LTS ≥ 1	LTS ≥ 2	LTS ≥ 3	LTS ≥ 4
Street width (through lanes per direction)	1	(no effect)	2 or more	(no effect)
Sum of bike lane and parking lane width (includes marked buffer and paved gutter)	15 ft. or more	14 or 14.5 ft.*	13.5 ft. or less	(no effect)
Speed limit or prevailing speed	25 mph or less	30 mph	35 mph	40 mph or more
Bike lane blockage (typically applies in commercial areas)	rare	(no effect)	frequent	(no effect)

Note: (no effect) = factor does not trigger an increase to this level of traffic stress.
* *If speed limit < 25 mph or Class = residential, then any width is acceptable for LTS 2.*

Table 9: Criteria for Bike Lanes Not Alongside a Parking Lane

	LTS ≥ 1	LTS ≥ 2	LTS ≥ 3	LTS ≥ 4
Street width (through lanes per direction)	1	2, if directions are separated by a raised median	more than 2, or 2 without a separating median	(no effect)
Bike lane width (includes marked buffer and paved gutter)	6 ft. or more	5.5 ft. or less	(no effect)	(no effect)
Speed limit or prevailing speed	30 mph or less	(no effect)	35 mph	40 mph or more
Bike lane blockage (may apply in commercial areas)	rare	(no effect)	frequent	(no effect)

Note: (no effect) = factor does not trigger an increase to this level of traffic stress.

Table 10: Criteria for Level of Traffic Stress in Mixed Traffic

	Street Width		
Speed Limit	2-3 lanes	4-5 lanes	6+ lanes
Up to 25 mph	LTS 1* or 2*	LTS 3	LTS 4
30 mph	LTS 2* or 3*	LTS 4	LTS 4
35+ mph	LTS 4	LTS 4	LTS 4

Note: * Use lower value for streets without marked centerlines or classified as residential and with fewer than 3 lanes; use higher value otherwise.

Table 11: Level of Traffic Stress Criteria for Pocket Bike Lanes

Configuration	Level of Traffic Stress
Single right-turn lane up to 150 ft. long, starting abruptly while the bike lane continues straight, and having an intersection angle and curb radius such that turning speed is ≤ 15 mph.	LTS ≥ 2
Single right-turn lane longer than 150 ft. starting abruptly while the bike lane continues straight, and having an intersection angle and curb radius such that turning speed is ≤ 20 mph.	LTS ≥ 3
Single right-turn lane in which the bike lane shifts to the left but the intersection angle and curb radius are such that turning speed is ≤ 15 mph.	LTS ≥ 3
Single right-turn lane with any other configuration; dual right-turn lanes; or right-turn lane along with an option (through-right) lane.	LTS = 4

Table 12: Level of Traffic Stress Criteria for Mixed Traffic in the Presence of a Right Turn

Configuration	Level of Traffic Stress
Single right-turn lane with length ≤ 75 ft. and intersection angle and curb radius limit turning speed to 15 mph.	(no effect on LTS)
Single right-turn lane with length between 75 and 150 ft., and intersection angle and curb radius limit turning speed to 15 mph.	LTS ≥ 3
Otherwise.	LTS = 4

Table 13: Level of Traffic Stress Criteria for Unsignalized Crossings without a Median Refuge

Speed Limit of Street Being Crossed	Width of Street Being Crossed		
	Up to 3 lanes	4 - 5 lanes	6+ lanes
Up to 25 mph	LTS 1	LTS 2	LTS 4
30 mph	LTS 1	LTS 2	LTS 4
35 mph	LTS 2	LTS 3	LTS 4
40+	LTS 3	LTS 4	LTS 4

Table 14: Level of Traffic Stress Criteria for Unsignalized Crossings with a Median Refuge at least Six Feet Wide

Speed Limit of Street Being Crossed	Width of Street Being Crossed		
	Up to 3 lanes	4 - 5 lanes	6+ lanes
Up to 25 mph	LTS 1	LTS 1	LTS 2
30 mph	LTS 1	LTS 2	LTS 3
35 mph	LTS 2	LTS 3	LTS 4
40+	LTS 3	LTS 4	LTS 4