Intersections as Barriers to Low-Stress Cycling:

Intersection Level of Traffic Stress and Dual-Graph Network Modeling

Nathan David Obeng-Amoako & Peter Furth
Department of Civil & Environmental Engineering
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Everyday Cycling: Good for People, Planet, and Cities

1. Zero-emission trips
2. Free Daily Exercise
3. Low cost to ride
4. Better mental health
5. Healthy child development
6. Ridable year-round

One Thing Stands in the Way: High Traffic Stress

Levels of Traffic Stress (Segments)

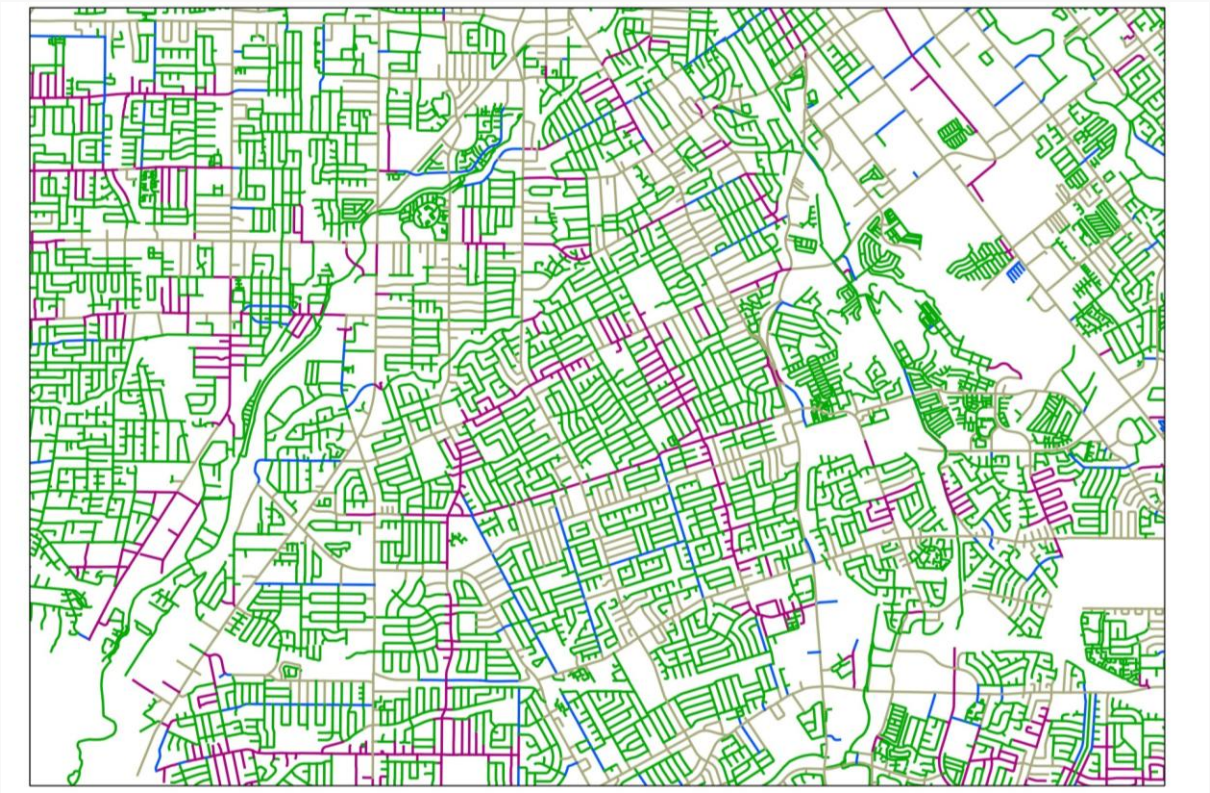
Level 1

Level 2

Level 3

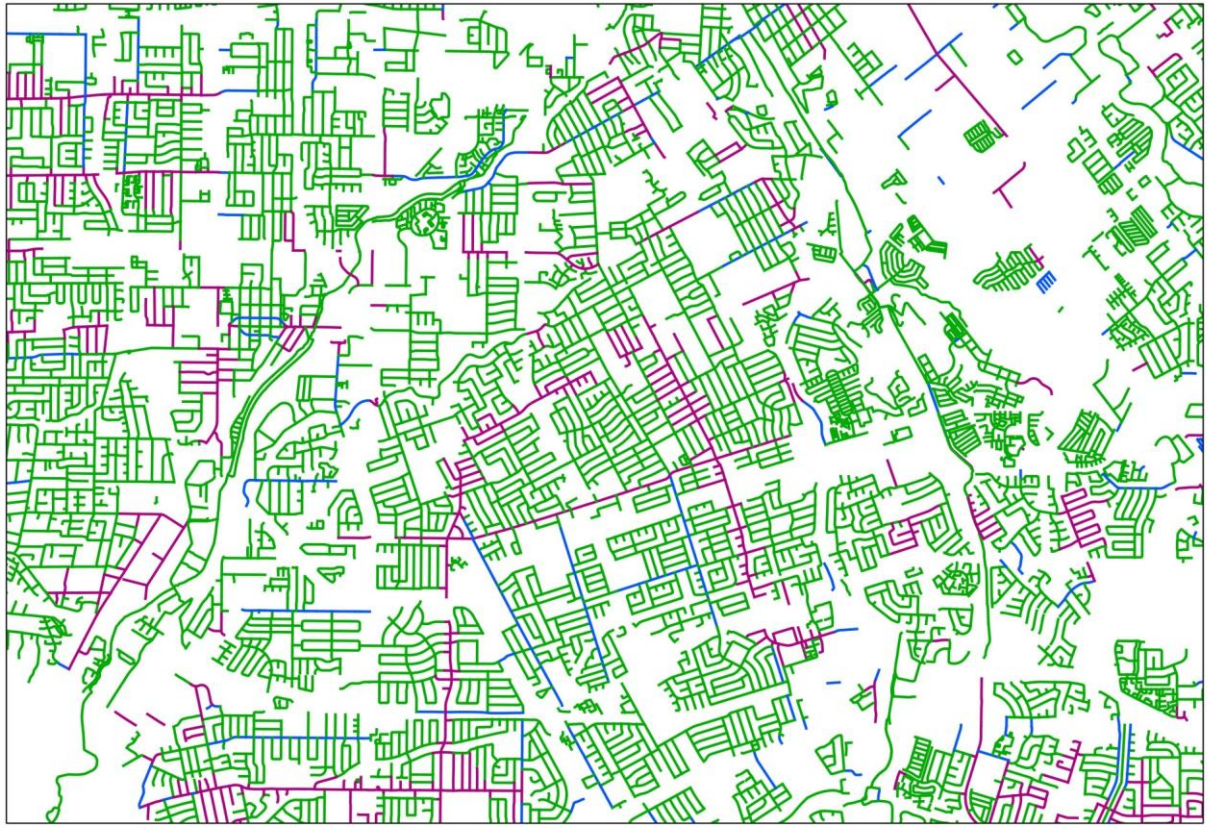
Level 4

San Jose 2010, All Levels of Traffic Stress

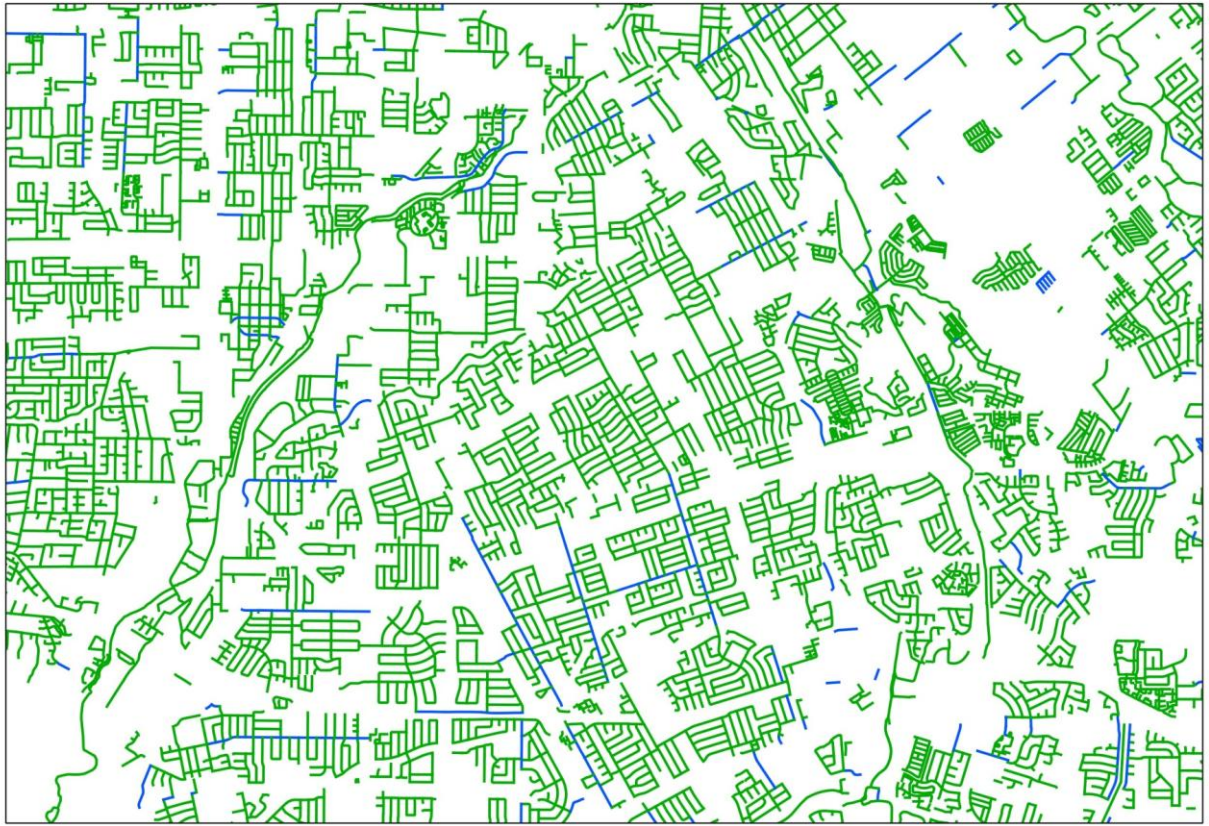


Green = LTS 1, Blue = LTS 2, Purple = LTS 3, Tan = LTS 4

Stress Level 3 or Less



Stress Level 2 or Less



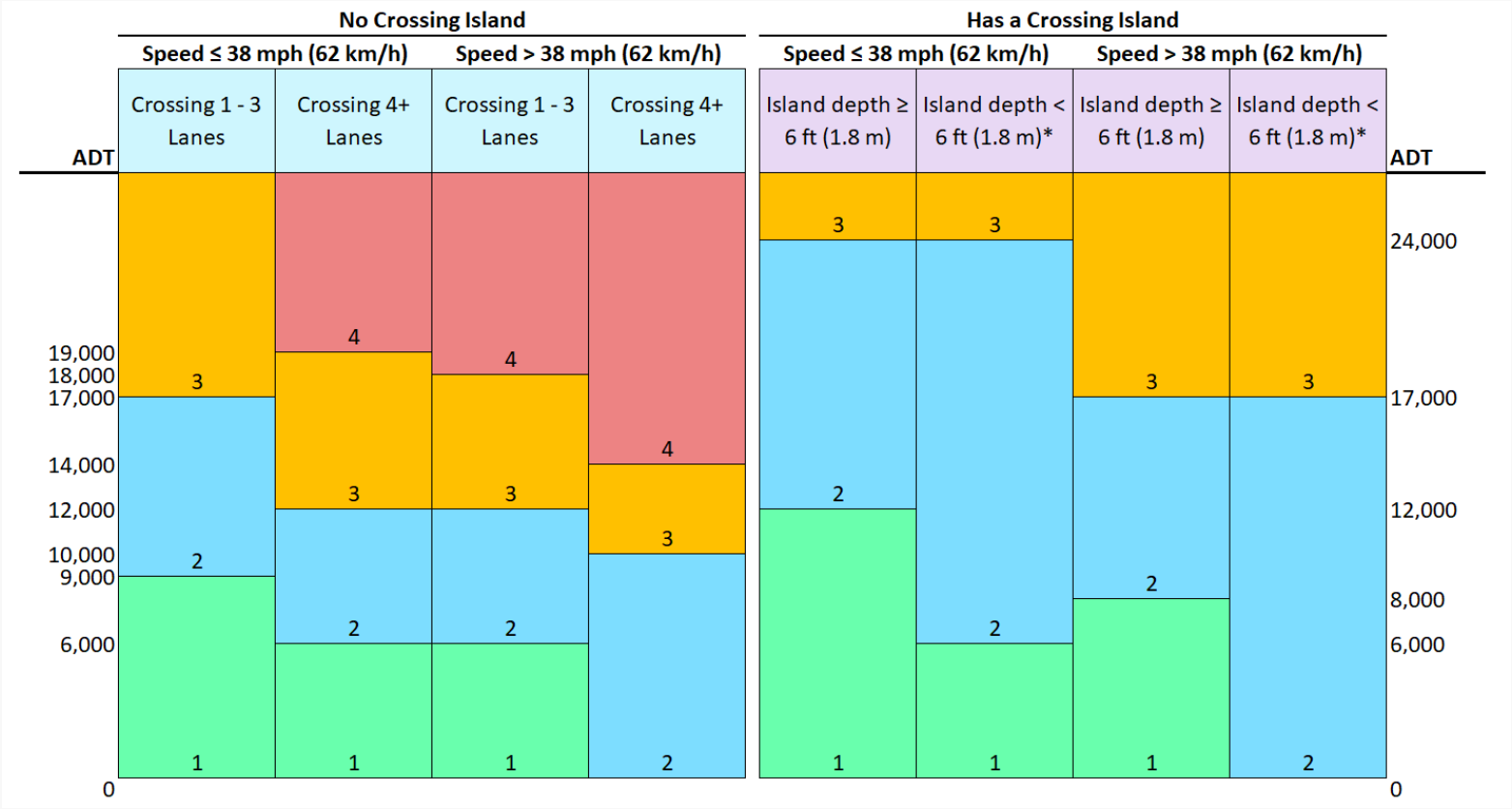
Stress Level 1

Intersection Level of Traffic Stress

Signalized Crossings are OK, Except for Some Higher-Stress Triggers

Factor	Condition	xLTS 2 trigger	xLTS 3 trigger
Crossing distance	No bike signal and no crossing island ≥ 6 ft (1.8 m) deep	crossing distance > 100 ft (30 m)	
Permitted right-turn volume (peak hour)	Bike box or head-start interval provided	RT volume > 5.5 per signal cycle (or 200/h where cycle length unknown)	
	Otherwise	RT volume > 3.5 per signal cycle (or 120/h where cycle length unknown)	
Permitted left-turn volume (peak hour)	Multilane road with permitted left-turn conflict with bike crossing	Permitted LT volume > 1.5 per signal cycle (or 50/h where cycle length unknown)	
Permitted right-turn speed	Right turns with permitted conflict with the bike crossing	Corner geometry allows turning speed > 15 mph (24 km/h)	> 22 mph (35 km/h)
Multistage crossing	Bikes must cross in 2+ stages and wait in a traffic island	crossing island depth < 100 ft (30 m)	

Crossing Stress (xLTS) for Unsignalized, Non-Priority Crossings



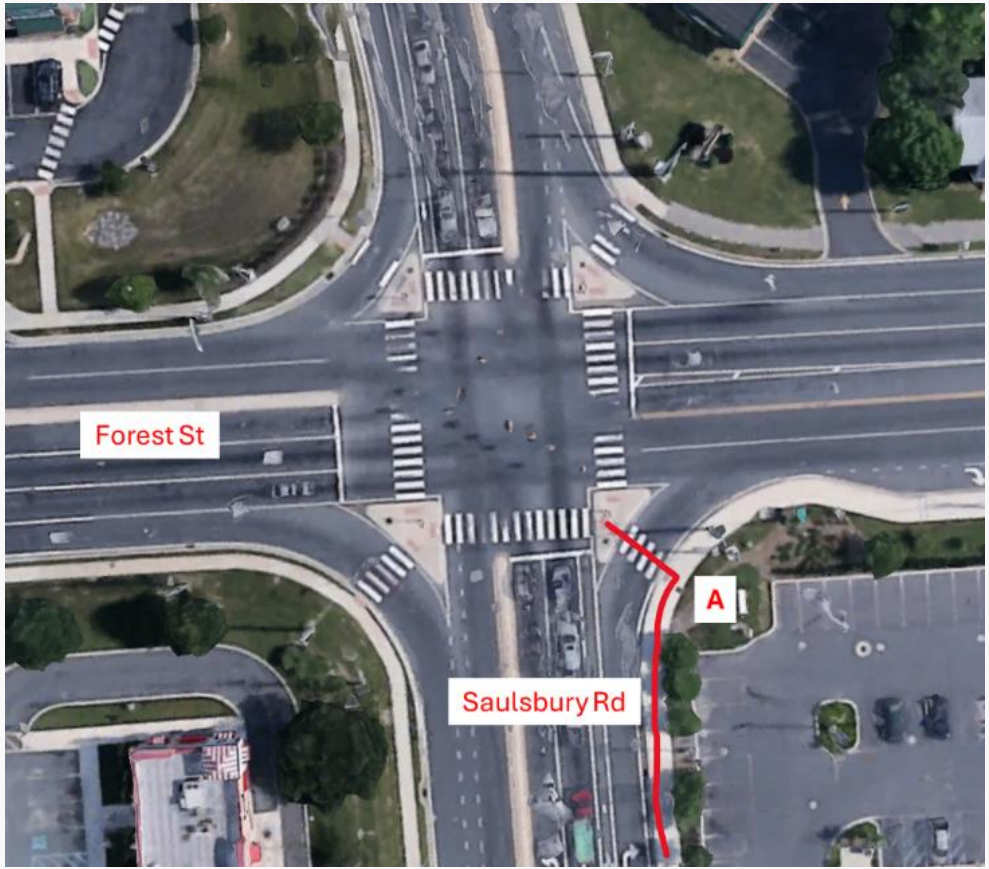
Gap Acceptance Model to Combine Parameters into a Consistent Model

User class	Speed (ft/s)	Start-up offset (s)	Post-encroachment time (s) by traffic speed				Maximum average delay (s)
			≤ 30 mph	35 mph	45 mph	55 mph	
LTS 1 (children)	8.8	4.4	2.0	25	4.3	5.8	25
LTS 2 (most adults)	11.0	3.4	1.0	35	2.5	3.5	35
LTS 3 (bike enthusiasts)	14.7	2.4	1.0	180	2.5	3.5	180

Unsignalized Trail Crossings (One Lane per Direction)

RRFB?*	ADT	Speed ≤ 28 mph (46 km/h)		28–38 mph (46–62 km/h)		Speed > 38 mph (62 km/h)
		No island	With island	No island	With island	
No RRFB	≤ 8,000	xLTS 1	xLTS 1	xLTS 1	xLTS 1	*Use **Exhibit 2***
	> 8,000	*Use **Exhibit 2***	xLTS 1	*Use **Exhibit 2***	*Use **Exhibit 2***	*Use **Exhibit 2***
With RRFB	Any	xLTS 1	xLTS 1	xLTS 1	xLTS 1	*Use **Exhibit 2***

Blind Entry Hazard



Cyclists have to look **back** to see conflicting traffic

Freeway Ramp Crossings & Blind Entry Hazards

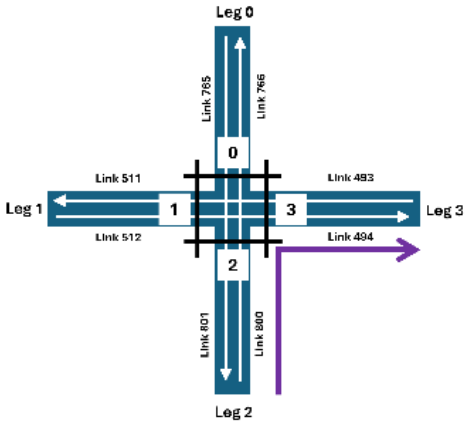
Factor	Condition	xLTS 2 trigger	xLTS 3 trigger
Crossing an on-ramp (ramp from bicycling road to freeway)	Does not apply where conflicting traffic has a stop sign	Departure road 85th percentile speed < 33 mph (54 km/h) OR road geometry requires ramp entry speed < 15 mph (24 km/h)	Other on-ramp crossing
Crossing an off-ramp (ramp from freeway to bicycling road)	Does not apply where conflicting traffic has a stop sign	Receiving road 85th percentile speed < 38 mph (62 km/h) OR ramp speed at crossing ≥ 31 mph (50 km/h) OR crossing crosses ramp at a right angle	Other off-ramp crossing
Blind entry hazard		Cyclists enter a crossing from a path with less than 4 ft (1.2 m) separation from the roadway, requiring them to look backwards to scan for conflicting traffic before turning to enter the crossing. “Conflicting traffic” excludes permitted turns from a lane used primarily by thru traffic.	—

Calculating and Visualizing xLTS

Movement LTS (mLTS) vs Crossing LTS (xLTS)

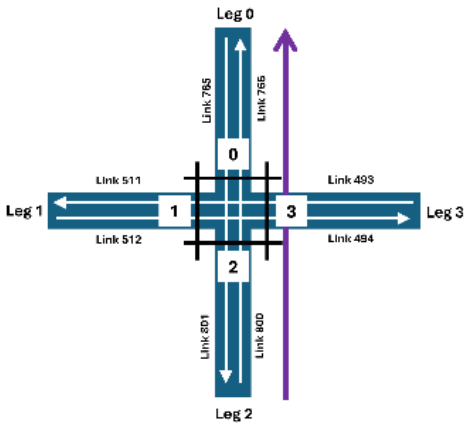
$$mLTS = \max(xLTS_1, xLTS_2, \ldots)$$

RIGHT TURN (800 → 494)



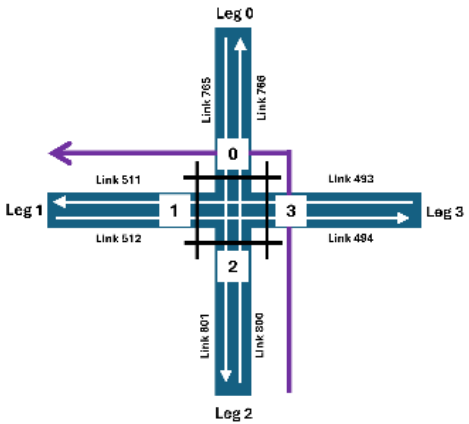
Crossing no legs
mLTS(800, 494) = 1

THRU' MOVEMENT (800 → 766)



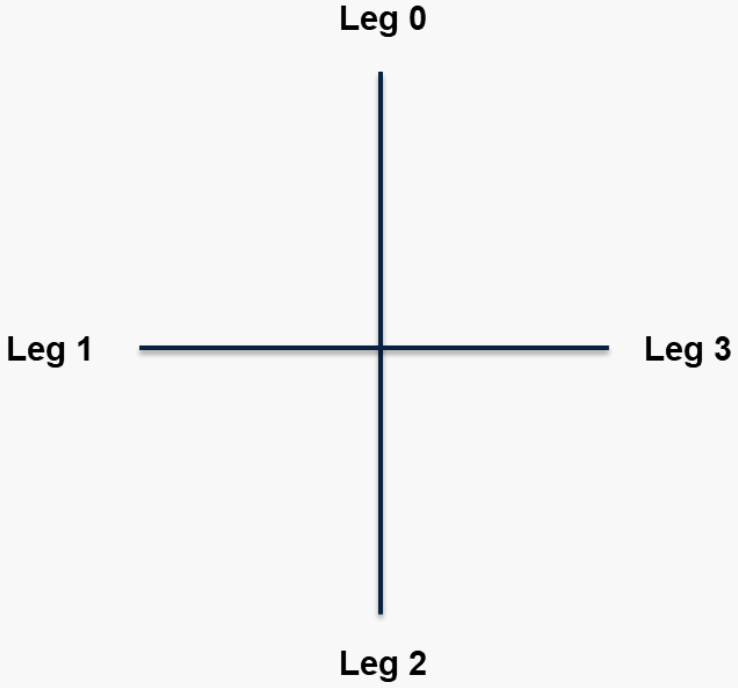
Crossing leg 3
mLTS(800, 766) = xLTS(3)

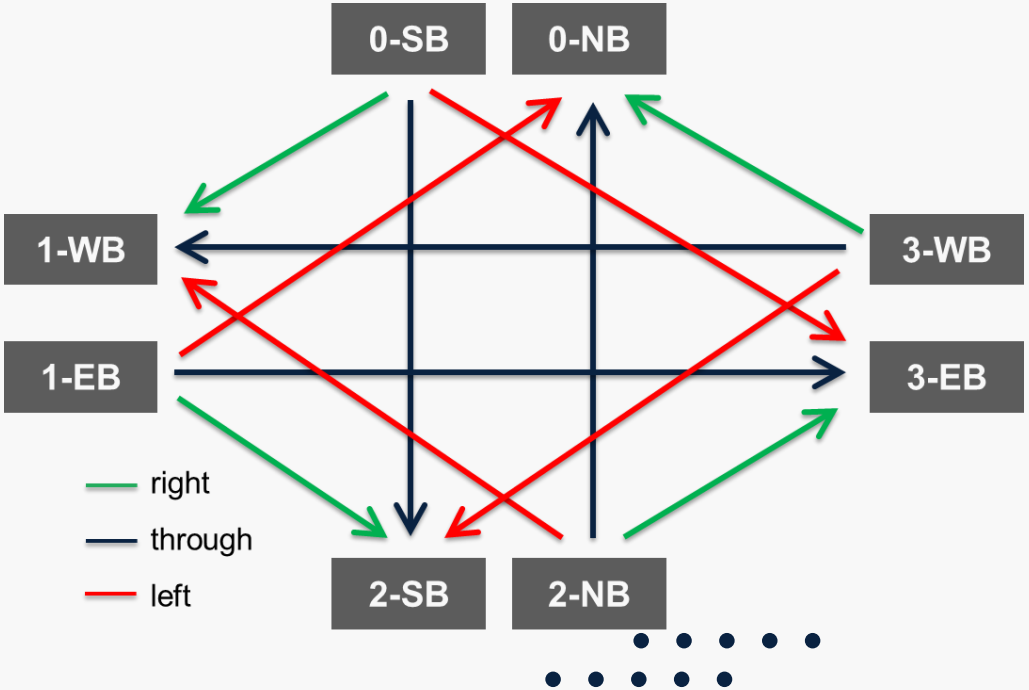
LEFT TURN (800 → 511)



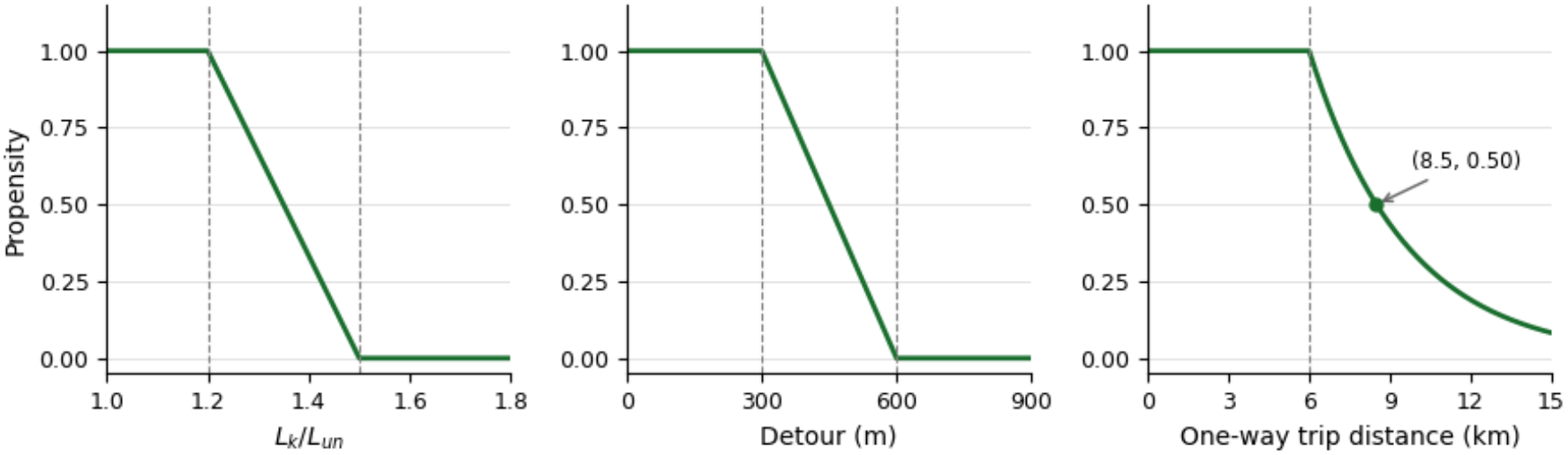
Crossing legs 3 and 0
mLTS(800, 511) = max[xLTS(3), xLTS(0)]

Dual Graph Representation Needed to Model Turning Costs





Propensity for Relative Detour, Absolute Detour and Total Distance



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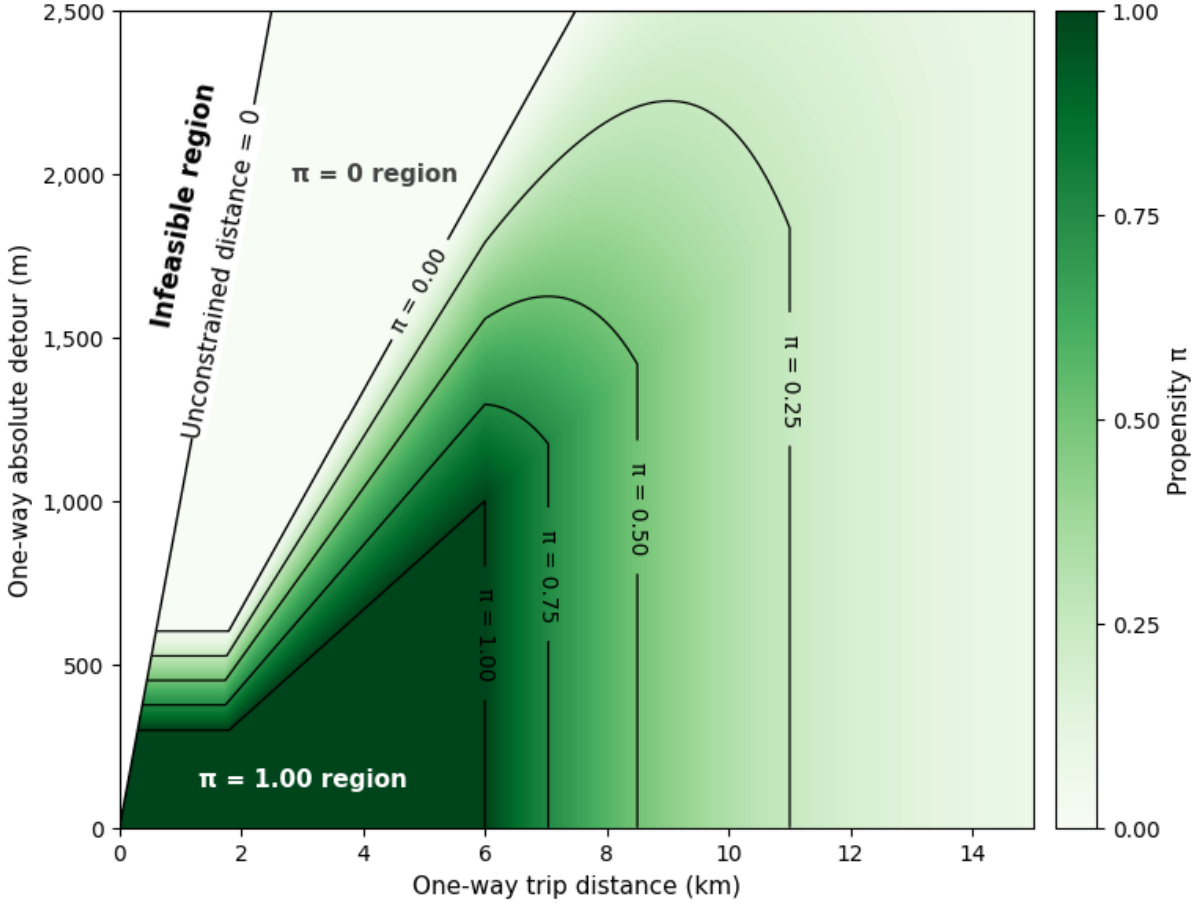
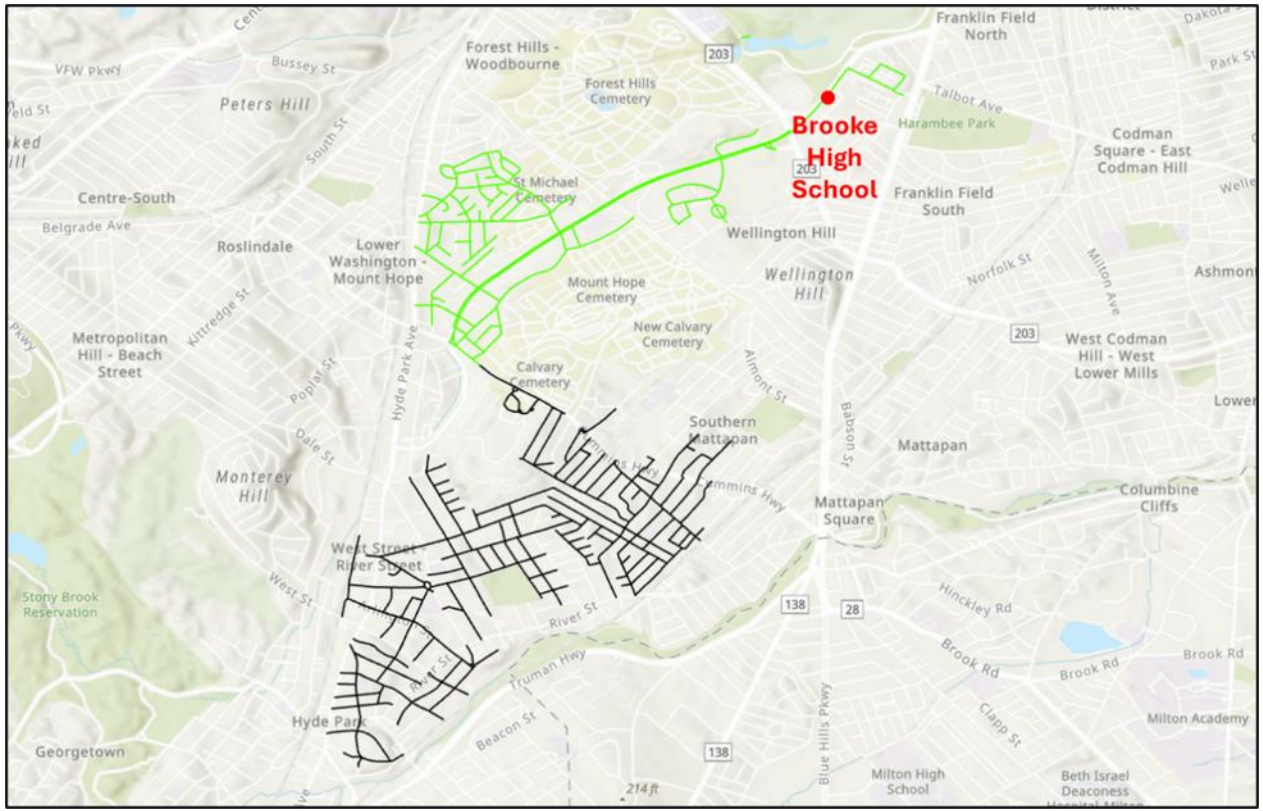


Applying xLTS to Job Accessibility in Boston

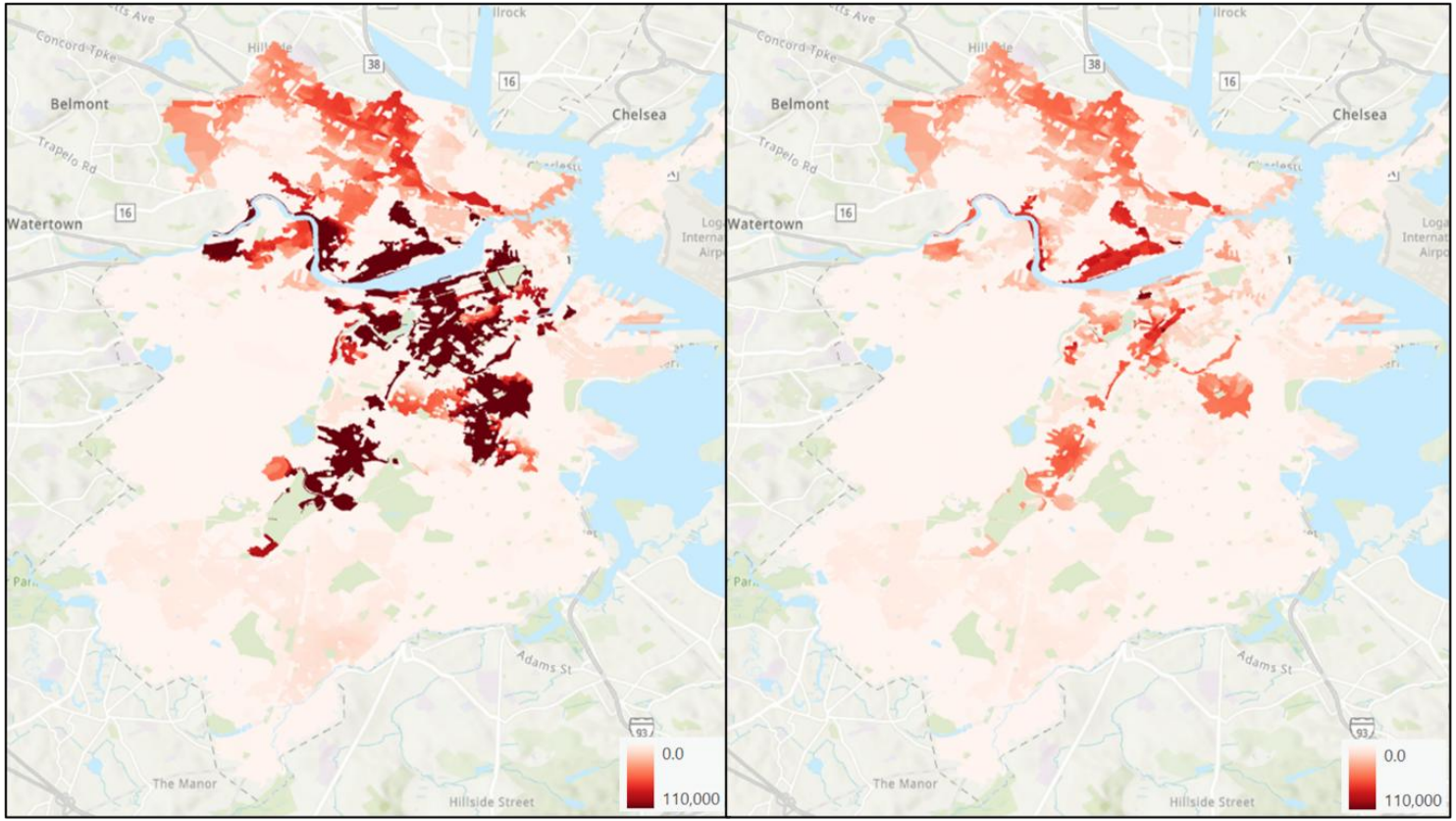
High Stress Crossing Limiting Accessibility



City-Wide Bike Accessibility to Jobs in the Boston Area by LTS

Stress limit	xLTS not enforced	xLTS enforced
LTS 1	9,056 (0.9%)	2,339 (0.2%)
LTS 2	116,036 (12.1%)	103,892 (10.9%)
LTS 3	515,543 (51.4%)	511,517 (51.0%)
LTS 4	575,152 (57.4%)	575,152 (57.4%)

Job Accessibility at LTS 1, Ignoring xLTS (LEFT) Versus Accounting for xLTS (RIGHT)



Job Accessibility at LTS 2, Ignoring xLTS (LEFT) Versus Accounting for xLTS (RIGHT)