Cyclist Behaviour and Safety Towards Stop Signs. A Study on Stop-Controlled Intersections Using Video Trajectory and Surrogate Measures of Safety

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Introduction

Despite the existing body of knowledge, some significant controversies and limitations in the current literature can be highlighted regarding AWS intersections in the North American standards:

- Stop signs have been used in many cases as a traffic calming measure to reduce vehicular speeds and traffic volumes going through residential areas, while stop signs are explicitly forbidden to be used for traffic calming by manuals and guidelines
- Despite the popularity of converting MAS to AWS intersections in urban areas, there is little research on the impacts of this countermeasure on cyclist safety and their behaviour.
- Finally, existing studies have focused on vehicles and pedestrian safety, with very few looking at cyclist safety.

Objectives

This research investigates the cyclist behaviour at stop signs and the safety effects of converting MAS to AWS intersections using a before-after observational approach and surrogate measures of safety (SMoS). i.e. measures of safety that do not depend on the occurrence of crashes.

- A multi-level modelling approach is used to evaluate the impact of the introduction of stop-signs on all approaches controlling for cyclist behaviour (using a helmet, making an avoidance maneuver or making a full stop), built environment, approach and intersection geometry.
- Among the SMoS, this research considers various cyclist speed measures and the post-encroachment time (PET) for cyclist-pedestrian, cyclist-cyclist and cyclist-vehicle interactions.

Intersection Geometry and User's Attributes

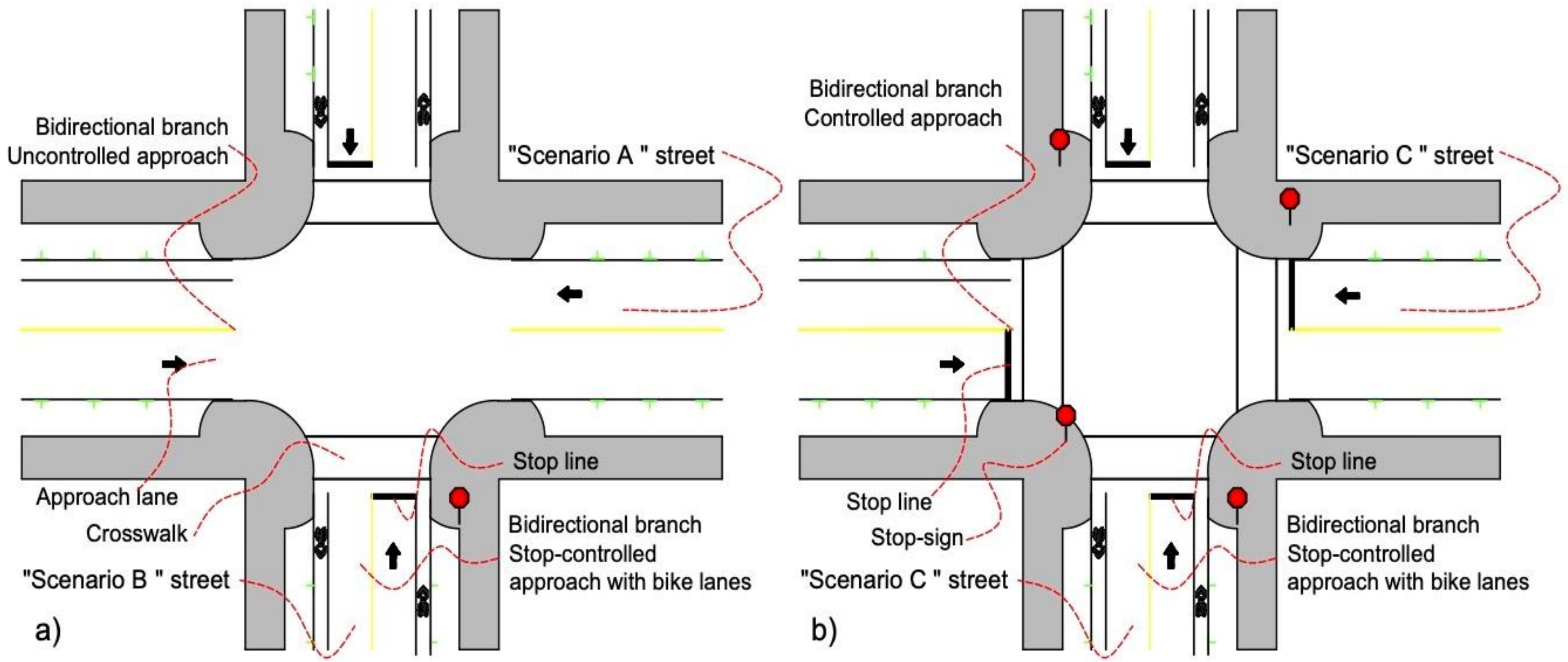
Stop -Control Scenarios: A set of three different conditions or scenarios were defined to evaluate the effect on the cyclist of the traffic control devices as follows:

Scenario A, for the users coming from an approach with no stop sign. These approaches are on a MAS intersection, evaluating the cyclists' behaviour when there is no traffic control in their path (major approaches).

Scenario B, for the users coming from an approach with a stop sign. These approaches (minor approach) are also part of a MAS intersection, defined to evaluate the cyclists' behaviour when there is a stop sign in their path.

Scenario C, defined for the user's coming from any approach with a stop sign belonging to an AWS intersection.

Intersection Geometry and User's Attributes



Example of the three scenarios on an intersection with four branches and four legs. a) scenario A and B; b) scenario C

Safety Indicators

The safety analysis performed in this study makes use of the following safety indicators that are part of the surrogate safety approach:

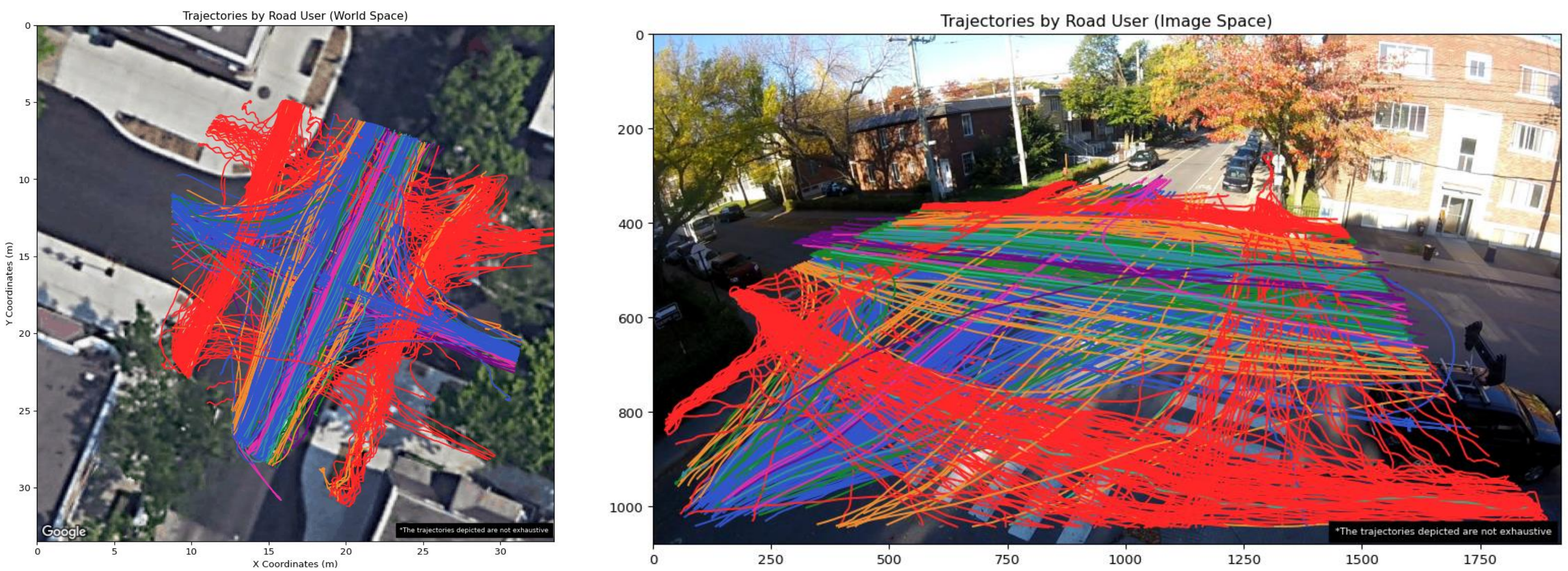
- ***Road users speed***: the minimum calculated as the 15th percentile ($v_{15^{th}}$), median (v_{med}), average (avg) and maximum calculated as the 85th percentile ($v_{85^{th}}$) speed.
- ***Post-Encroachment Time (PET)***: The PET is calculated as the time difference where the first road-user (user “a”) leaves the path or crossing zone before the second road-user reaches the mentioned zone (user “b”)
- **PET categories:** PET values are divided into severity categories according to their values:
  - Dangerous, PET ≤ 1.5 s
  - Mild, 1.5 s < PET ≤ 3 s
  - Safe, 3 s < PET ≤ 5 s
- In addition to safety indicators, three cyclist variables about their behavior were manually observed: the use of a helmet, an avoidance maneuver by the cyclist during the interaction or the cyclist coming to a full stop.

Video data collection and processing

- Sites were instrumented using regular video action cameras installed in the intersection’s proximity, typically on a nearby lamp post.
- The sites’ instrumentation took place during weekdays on working days, during peak and non-peak hours.
- There is one year of difference between the before and after data collection.
- The video was collected on each selected site for one day before the treatment, and one day after it, between 8 am and 6 pm.
- Data were then processed to extract high-resolution road user trajectories at each site with the help of TrafxSafe, a commercial software from Transoft. This software automatically identifies, tracks and classifies each road user into one trajectory and labels them as pedestrians, bicycles, motor-vehicles and unknown.

Video data collection and processing

Once trajectory data is automatically generated, a manual review was carried out to correct VRU trajectories and to annotate the users' behaviour used in this research; this process was accomplished using the tvaLib software (not maintained anymore)



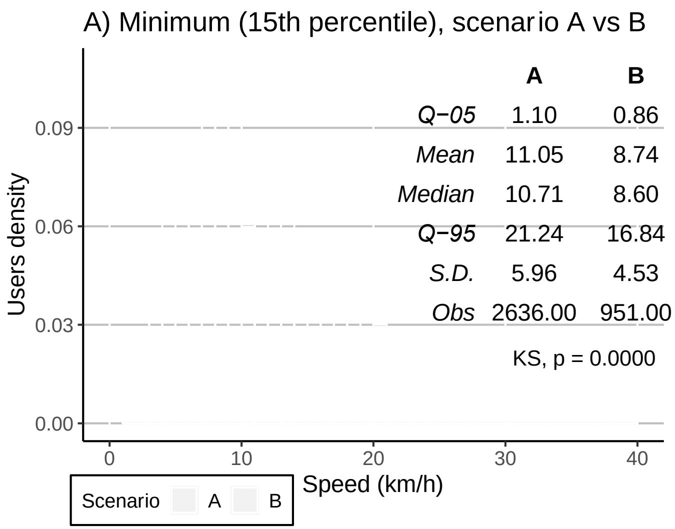
Example of processed video trajectories. Left) represents the trajectories on a world space picture, while Right) represents the trajectories on the image space.

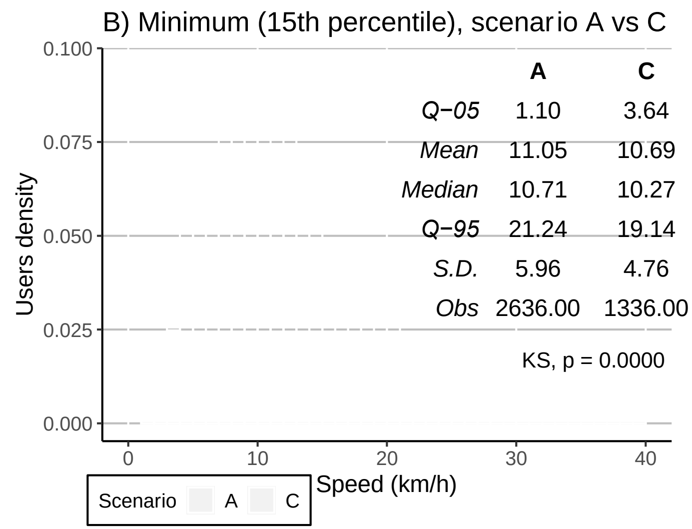
Data Inventory

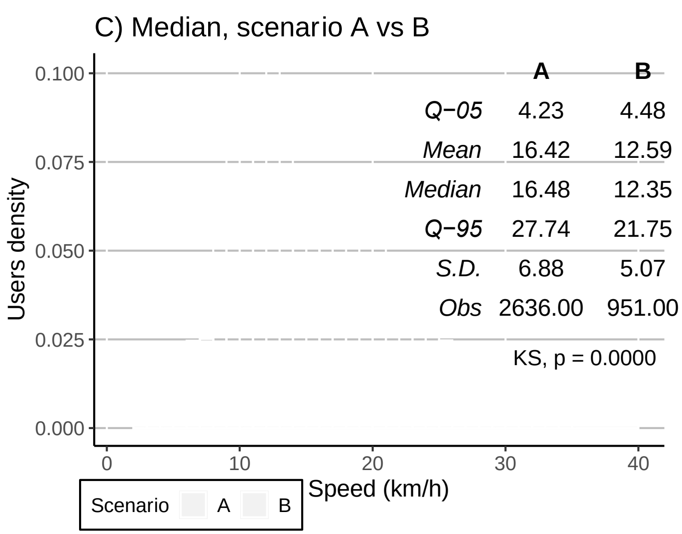
Intersection's data inventory collected from 8 am to 12 pm for each intersection

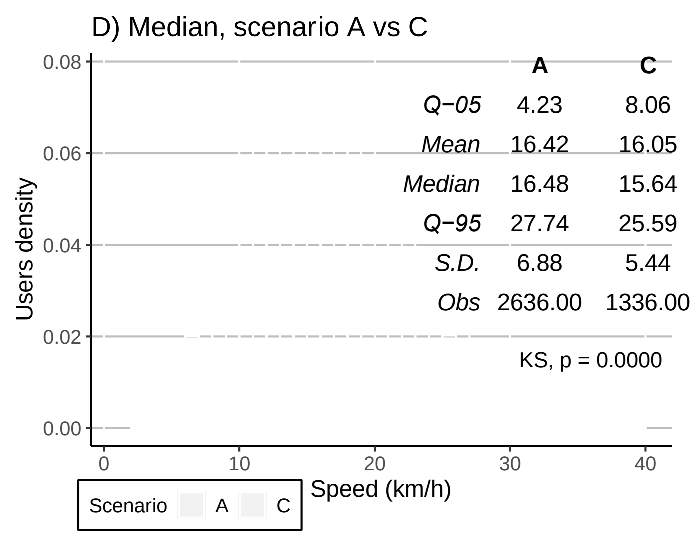
Definition	Scenarios counts				Hourly Ratio		
	A	**B**	**C**	**Total**	**A**	**B**	**C**
Pedestrians	4,914	1,537	3,692	10,143	35.1	11.0	30.8
Cyclist	2,636	951	1,336	4,923	18.8	6.8	11.1
Motorized	26,163	6,868	23,358	56,389	186.9	49.1	194.7
Total number of users	**33,713**	**9,356**	**28,386**	**71,455**	240.8	66.8	236.6
Video data (h)	140		120	260		-	
Total approaches		109				-	
Distinct intersections		35				-	
Three branches		12				-	
Four branches		21				-	

Speed Profiles Comparison









Regression Model and Results

Cyclist Summary Statistics of variables for statistical analysis (Part 1)

	Variable	Min	Mean	Max	PET
User attributes	(Intercept)	13.890***	17.730***	21.970***	2.727***
	Movement B	-0.424*	-1.089***	-1.538***	0.088
	Movement C	-0.403	-1.365***	-1.693***	0.031
	Helmet	0.479***	0.747***	0.968***	-0.101
	Avoid	-2.156**	-2.948***	-2.518**	-0.928*
	Stop	-6.690***	-7.590***	-5.245***	0.771
	Exposure	-0.147***	-0.153***	-0.199***	-
	Cyclist - Cyclist	-	-	-	-0.393*
	Cyclist - Vehicle	-	-	-	0.633***
Approach-level	Scenario B	-4.490***	-3.867***	-2.341***	0.186
	Scenario C	-1.782***	-1.072**	-0.622	0.244*
	Presence of vehicle stop line	-	-	-	-
	Presence of Crosswalk	0.203	0.151	-0.548	-0.635*
	Type of crosswalk	-	-	-	-
	Bike-path at the approach	-1.009*	-0.336	0.168	+
	Approach width at the crosswalk level	+	+	+	+
	Approach width 10 m upstream	+	+	+	+
	Number of lanes	1.236*	2.236**	2.102*	0.312*

Note: *p<0.1; **p<0.01; ***p<0.001
+ Dropped variables due high correlation between independent variables
- Variable not evaluated in the model

Regression Model and Results

Cyclist Summary Statistics of variables for statistical analysis (Part 2)

	Variable	Min	Mean	Max	PET
Intersection-level	Distance to previous intersection	0.001	0.001	-0.004	0.001
	Previous intersection stops	-0.908	-0.202	0.639	0.264
	Previous intersection traffic	-0.445	0.738	1.460	0.216
	Number of branches (four branches)	0.202	0.524	1.219	-0.036
	Number of approaches	+	+	+	+
	Bike-path (shared road)	-	-	-	-0.541**
	Painted bike lane	-	-	-	-0.221
	Separated Bike path	-	-	-	-0.437
	Built environment variables				
	Population density	-0.027	-0.034*	-0.03	-0.004
	Employment density	0.032*	0.027	0.004	0.008*
	Land use mix	-	-	-	-
	Transit accessibility	-	-	-	-
Model	Random Effect				
	Site	1.96	2.13	2.12	0.01
	Approach	1.8	2.12	2.3	0.17
	Residual	4.36	5.06	5.43	1.16

Note: *p<0.1; **p<0.01; ***p<0.001
+ Dropped variables due high correlation between independent variables
- Variable not evaluated in the model

Regression Model and Results

Cyclist speed, PET model and ANOVA analysis

Coefficients	Minimum	Median	Maximum	PET
Observations		4,923		678
Site Number		35		25
Groups number *		121		58
Pseudo-R2 Marginal	0.167	0.175	0.143	0.108
Pseudo-R2 Conditional	0.394	0.390	0.360	0.127
AIC	28,737	30,213	30,889	2,226
ANOVA test (p-value)				
Helmet	**0.001**	**0.001**	**0.001**	**0.001**
Wavering vs Full stop	**0.001**	**0.001**	**0.015**	**0.009**
Period	**0.001**	**0.001**	**0.001**	**0.001**
Stop Sign	**0.001**	**0.001**	**0.001**	**0.001**

* Group number, refers to the total number of different approaches.

Cyclist PET Interactions range

Cyclists PET Interactions range

Scenario	PET Range (%) 0 - 1.5 (Dangerous)	PET Range (%) 1.5 - 3.0 (Mild)	PET Range (%) 3.0 - 5.0 (Safe)	Total	Rate per 10,000 cyclists 0 - 1.5 (Dangerous)	Rate per 10,000 cyclists 1.5 - 3.0 (Mild)	Rate per 10,000 cyclists 3.0 - 5.0 (Safe)
Pedestrians							
A	13 (28.9)	13 (28.9)	19 (42.2)	45	0.019	0.019	0.027
B	1 (4.8)	9 (42.9)	11 (52.4)	21	0.011	0.100	0.122
C	16 (32.0)	19 (38.0)	15 (30.0)	50	0.090	0.106	0.084
Cyclists							
A	5 (29.4)	5 (29.4)	7 (41.2)	17	0.007	0.007	0.010
B	5 (45.5)	2 (18.2)	4 (36.4)	11	0.055	0.022	0.044
C	4 (57.1)	3 (42.8)	0 (0.0)	7	0.022	0.017	0.000
Vehicles							
A	20 (8.8)	85 (37.3)	123 (53.9)	228	0.029	0.122	0.177
B	6 (4.32)	57 (41.0)	76 (54.7)	139	0.066	0.630	0.840
C	9 (5.3)	60 (35.5)	100 (59.2)	169	0.050	0.336	0.560

Note: (percentage of the interactions in the scenario)

Conclusions

- It was found that there is not a significant safety improvement (PET) in the approaches with stop signs. However, when cyclists interact with other cyclists, the PET's values are lower (negative effect) than the PET's values of the interaction with pedestrians or vehicles (significant values).
- It should be noted that the mean PET value of a cyclist with a pedestrian and a vehicle are similar (2.30 s).
- Cyclists will show a significant speed reduction when there is a stop sign signal at the approach. It is a major speed reduction when the cyclists come from an approach with a stop sign (MAS intersection, scenario B) of 4.49 km/h, compared to a scenario when all the users have to stop (AWS, scenario C) of 1.78 km/h.
- Stops signs do not significantly affect cyclist behaviour, compared to the different reactions they are already having with the different users of the road.

Thank you for your attention

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