INVESTIGATION OF THE EFFECT OF SUPER-SHARROWS ON CYCLIST AND VEHICLE BEHAVIOR

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ABSTRACT:

This study examines the potential effect of special paintings of shared lane markings (super-sharrows), on a number of operational and safety performance parameters for cyclists and motor vehicles. These performance parameters were used to assess the pre- and post-treatment behavior when cyclists and motor vehicles are in close proximity. The performance parameters are: [i] rate of lane change maneuvers performed by vehicles in the presence as well as absence of cyclists and [ii] lateral spacing between cyclists, vehicles, and curb edge. In general, the main objectives of this treatment consist of [i] providing cyclists with comfort by riding in the middle of the travel lane, [ii] promoting safe passing by motor vehicles. The effect of the super-sharrows on both cyclists and motor vehicles were analyzed using statistical analysis by comparing pre- and post- treatment conditions. As a result, the key findings were [i] there was an increase in the percentage of motor vehicles that changed from the right (location of super-sharrows) to the left lane with the presence of a cyclist on the right lane, [ii] the proportion of motor vehicles that passed a cyclist while partially or fully encroaching to left lane decreased, [iii] the rate of motor vehicle lane change maneuvers from left to right lane decreased, [iv] the average lateral distances between bicycle and curb when a vehicle is adjacent increased from 0.59m to 0.69m, [v] the frequency of cyclists riding within 1.20m from the curb edge increased, and [vi] there was a reduction in the number of cyclists who rode on the sidewalk.

Keywords: Cyclists, sharrows, lane change maneuvers, lateral distance, video camera.

INTRODUCTION

Cyclists are vulnerable road users, yet capable of moving at a relatively high speed compared to other non-motorized modes. Due to these characteristics, cyclists are permitted to share the roadway with other motorized vehicles. The competition for space among these road users is often controlled by various traffic control measures. A challenging aspect of controlling motorized and non-motorized modes is when they share the same traffic lanes, especially when exhibiting variability in size and speed. In order to improve cycling safety, a wide-range of engineering treatments has been suggested. For example, [i] protected bicycle lanes, [ii] buffered bicycle lanes, [iii] colored conflict zone markings, and [iv] protected bicycle signal phase *(1)*. Among these, shared-lane markings are relatively inexpensive and do not require any additional space at the expense of sidewalks or other traffic lanes. This study focuses on a special configuration of shared-lane markings. The study compares the before (pre-treatment) and after (post-treatment) conditions for a treatment involving the painting of shared-lane marking with conspicuous green background in the middle of the outside lane, called in this study super-sharrows in an urban street in the City of Ottawa, Canada. This treatment is relatively new in the City and hence the study focused on one site only. The urban street was composed of two directions in total, two lanes each. The study section of this street was located on a bridge and extends to the entrance of the bridge, hence was on an uphill section. The rationale behind this site selection was the physical limitation of the right of way by the bridge structure. Hence, a cycle lane was challenging to allocate. Regular sharrows have been used with mixed results, hence super-sharrows were implemented with intent to evaluate them. The conspicuous visual specifications of the super-sharrows are intended to improve efficacy in promoting safe sharing of the traffic lane. More specifically, the objectives of this treatment can be described as follows:

1- Encourage cyclists to ride in the middle of the lane where the super-sharrows were implemented.
2- In order to promote safe passing, motor vehicles are encouraged to follow cyclists when passing distance is not safe.
3- In the presence of cyclists, motor vehicles who are reluctant to follow, are encouraged to completely change lanes when it is available.
4- To discourage cyclists from riding on sidewalks and to improve the safety for pedestrians.
5- To provide cyclists with enhanced comfort when riding in the middle of the travel lane, and not pushed to the often irregular pavement on the side or threatened by close overtaking.

In general, the main purpose of this study is to quantify change in cyclists and motor vehicles' behavior before and after implementation of supper-sharrows. In the next sections, this paper summarizes previous work, data collection, site description, analysis and results. A number of conclusions are listed at the end of this paper.

PREVIOUS WORK

Several shared lane marking have been implemented to encourage the safe co-existence of bicycles and motor vehicle *(2)*. Most common type is the standard sharrows. They are road markings used to indicate a shared lane environment for bicycles and motor vehicles. Sharrows are symbolized on the roadway as shown in Figure 1 in order to indicate that the travel lane is shared by both motor vehicles and cyclists *(3, 4)*. There are three main applications for the shared lane marking as shown in Figure 1 *(3)*. Besides shared lane marking, this indication was known as a bicycle stencil arrow when it was used at the first time in Denver, Colorado in 1993 *(5)*. This indication was used on signed bicycle routes where installation of a bicycle lane was not possible. The direction of the arrow indicates to cyclists the direction they should travel on the road. The repetition of the bicycle pattern alerts motor vehicle drivers to the potential presence of bicycles on that travel lane.

The "shared use arrow" was evaluated after producing a variation of the "bike-in-house" in Gainesville, Florida, in 1997 *(6)*. This designed paint was tested by placing it 0.76 meter from the curb in a travel lane without adjacent parking. Video tape was used to record bicycles and vehicles movements. Three spacing distances were measured; [i] bicycle to curb, [ii] bicycle to motor vehicle, and [iii] motor vehicle to curb. The result of a before/after evaluation showed that there was a statistically significant ($p< 0.01$) change in the number of cyclists who switched from sidewalk to road riding and the relative lane positions of vehicles and bicycles.

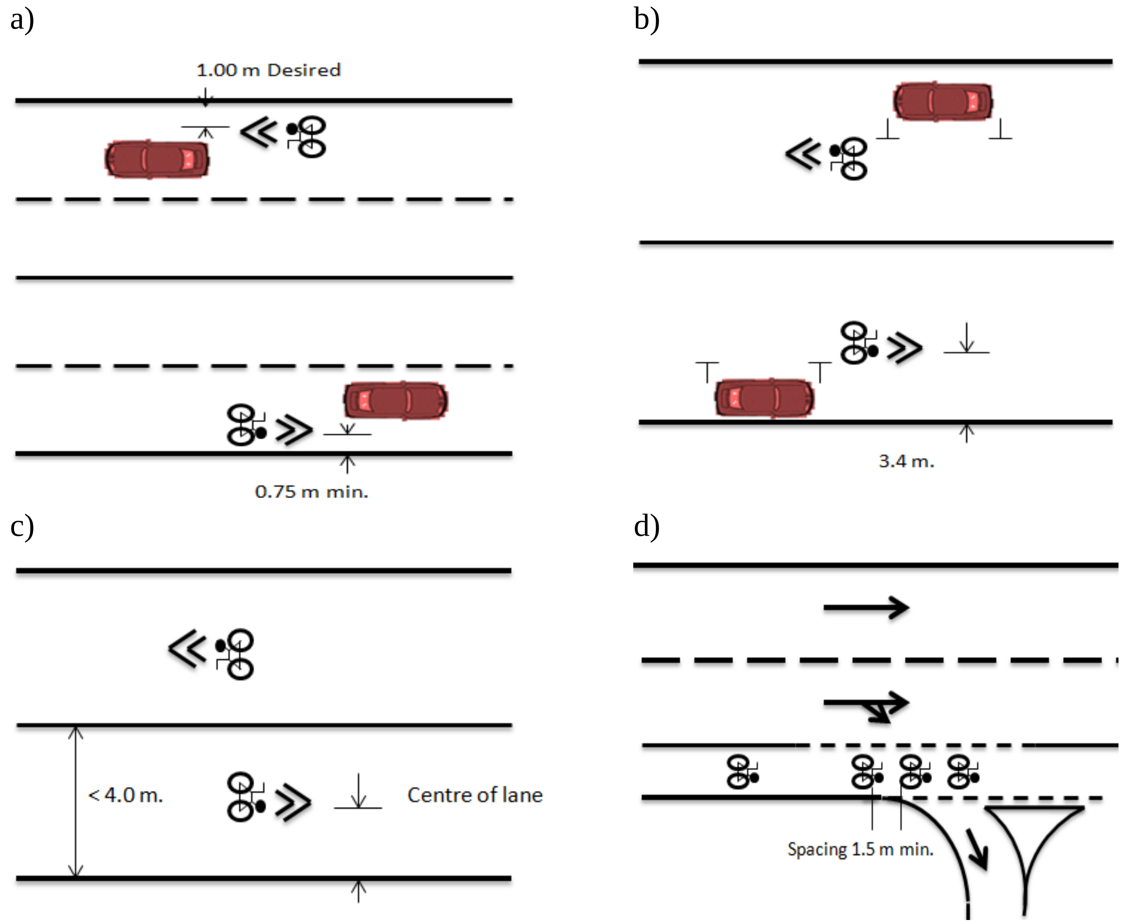


FIGURE 1: Schematic diagram of shared lane application: (a) side-by-side, no on-street parking. (b) side-by-side, full-time on-street parking. (c) single file operation. (d) conflict zone. (reproduced from (*3*)).

Several bicycle lane treatments were examined such as dashed-line edge, colored edge marking, solid edge marking, and sharrows using driving simulator in the University of Calgary in 2008. The results showed that sharrows had the highest (97%) level of comprehension and were the most obvious choice from a cyclist among these treatments *(7)*. In another study, sharrows were found to be significantly more attractive to potential users than a signed bicycle route alone *(8)*. When wide curb lanes are used without sharrows, it was found that both wrong-way riding and sidewalk riding were more frequent than at bicycle lane sites *(9)*. In a San Francisco study, it was found that the presence of sharrows was associated with reduced riding on the sidewalk by 35%, and reduced wrong-way riding by 80% *(10)*. The impact of sharrows on operational and safety measures for cyclists and motor vehicles was evaluated in *(2)*. Three different sharrow placements were implemented in three cities in the United States; [i] at a 3.05m (10 ft) distance from the curb on a four-lane street with parking in both sides, [ii] near the curb, on a busy five lane corridor and [iii] in the center of the downhill lane of a two-lane street. Video camera was used to collect the data and a number of measurements of effectiveness were coded such as: [i] whether the motor vehicle was passing or following a cyclist and [ii] whether the cyclist rode over the sharrows. In order to study the effect of sharrows on distance measurements, analysis of variance (ANOVA) were used. Results showed that sharrows increased operating space for cyclists and reduced sidewalk riding.

A before and after study of different sharrows marking in Gainesville, FL was conducted *(6)* and results concluded that the width of the lanes was wide enough to be shared side-by-side with bicycles and motor vehicles. The center of the sharrows marking was placed 1.07m (3.5 ft) from the curb. Three measurements were evaluated: [i] position of bicycle from the curb with/without motor vehicles present, [ii] space between motor vehicles and bicycles and [iii] position of a motor vehicle from curb when no bicycles present. Results showed that there was a significant increase in the proportion of cyclists riding in the street in the correct direction by 6% after sharrows were implemented. In addition, the average distance between cyclists and the curb before and after the sharrows were implemented, were found to be 0.49 m (1.6 ft) and 0.54 m (1.8 ft), respectively.

Another type of green shared lane was implemented in the City of Oakland *(11)*. This green-background shared-lane marking was called Super Sharrows while follows a “take–the-lane design approach”. It is painted as a sequence of green boxes which resemble sharrows made more conspicuous with a continuous green band (in contrast with the isolated green patches in this study) in the background with the intention of encouraging cyclists to ride through their center *(11*). This type of sharrows is an indication of shared space for both road users, with a visible reminder to motor drivers to look for cyclists and for cyclists to occupy the middle of the lane. Several reasons can be taken into consideration when adopting sharrows such as; [i] encouraging cyclists to travel away from the right-hand edge (side curb edge, adjacent parking lane and vehicle door opening zone) of the travel lane, [ii] alert motor vehicle drivers of the space cyclists are likely to occupy in the travel lane, [iii] encourage motor vehicle drivers to leave space for cyclists where lanes wide enough to share but where installation of bike lanes or other more exclusive bicycle facilities such as segregated bike lane is not possible, [iv] encourage proper cyclist behavior and reduce the incidences of wrong-way cycling.

DATA COLLECTION

Treatment Description

Super-sharrows are green rectangular (1.20 m x 3.0 m) stencils that were placed in the middle of the right travel lane (3.65 m wide) for every 25 meter spacing. This treatment was implemented on the uphill, and later on the downhill, section of the 40 km/h speed zone, located on Bank Street Bridge in the Downtown of the city of Ottawa, Ontario; as shown in Figure 2 *(12)*. The length of the treated section is 250 m.

Study Site and Equipment

For the purpose of examining if cyclist and/or motorist behavior changes with the introduction of super-sharrows, video camera was used to monitor cyclist and motor vehicle movements. The study area in this paper was the uphill section of the southbound direction of the Bank Street Bridge as shown in Figure 2 (*12*). In this study, video data was collected using static high-definition video camera (1920 x 1080 pixels, approximately 30 frames/second). Data collection was unobtrusive because the camera was placed at a point where the observed road users were unaware of video monitoring. Figure 3 (a) shows the camera's setup position. Figure 3 (b) and Figure 3(c) shows samples of the camera frames pre- and post-treatment.

Video Data Collection and Processing

Video data was collected in two different days (weekend approximately 9:00 AM - 4:00 PM and weekday approximately 8:00 AM – 5:00 PM) over eight days and for four different phases. Phase 1 video data collection (pre-treatment) was collected in May and June, 2014. Phase 2 was in August 2014 and was immediately after the super-sharrows implementation. Phase 3 (education phase) was in September 2014. The spacing between the green boxes was approximately 50 meters in these two phases. While phase 4 was collected in September and October 2015 (approximately one year after treatment). More super-sharrows were painted in this phase and the spacing between green boxes became approximately 25 meters. The education phase is the time after the site was visited by cycling and public safety advocates who performed outreach activities meant to inform cyclists of the purpose of the super-sharrows. These advocates were involved in creating and/or distributing education materials either through social media, media interviews or in person interactions on the road with residents. The weather on all days of the video data collection was clear. The super-sharrows design paint was placed in the center of the curb lane as shown in Figures 2 and 3 (c). The video data was labeled and converted to an appropriate formatting to enable further processing. Subsequences containing cyclists travelling in the uphill section (indicated in Figure 2) while occupying the road are identified. The volumes of the cyclists and the motor vehicles where the interactions are under investigation were counted for each lane at the beginning of the monitored section. A total of 2,437 cyclists and 33,205 motor vehicles were counted for all phases conditions.

Classification of Vehicle Lane Change Maneuvers

Motor vehicle lane change maneuvers were coded as follows: [i] the motor vehicle made no lane change, [ii] whether the motor vehicle made a full lane change maneuver from the right to the left lane (R-L) with/or without presence of a cyclist in front of this motor vehicle as shown in

Figure 4 (a), [iii] whether the motor vehicle made a full lane change maneuver from the left to the right lane (L-R) with/or without presence of an adjacent cyclist as shown in Figure 4 (b), [iv] whether the motor vehicle was following the cyclist who co-occupied the right lane as shown in Figure 4 (c), [v] whether the motor vehicle made a two-step lane change maneuver from the right to left and back to right lane with full encroachment into the left lane (R-L-R) or with partial encroachment to the left lane (R-R), all in presence of cyclists as shown in Figure 4 (d) and 4 (e).

Lateral Distances

In this study a close-proximity interaction between a cyclist and a motor vehicle was characterized based on the measurement of a lateral distance between road users. In the context of motor vehicle-cyclist interaction, the lateral distance is measured when their visible rear-ends are adjacent. This lateral distance was measured along the perpendicular distance on the right curb. Figure 5 shows a video frame that explains the measured lateral distance between cyclist and motor vehicle. As shown in Figure 5, the lateral distance was measured as the distance between [i] the estimated projection of the right rear part of the vehicle on the surface of the road pavement and [ii] the passing bicycle’s rear wheel contact point with the road pavement surface. In addition, at the same moment, the lateral distance between a cyclist and the right curb was measured. Distances were measured in pixel coordinates and then converted to meters based on geometric relationships between scale measured in meter/pixel perpendicular to curb edge and location developed for each camera setting.

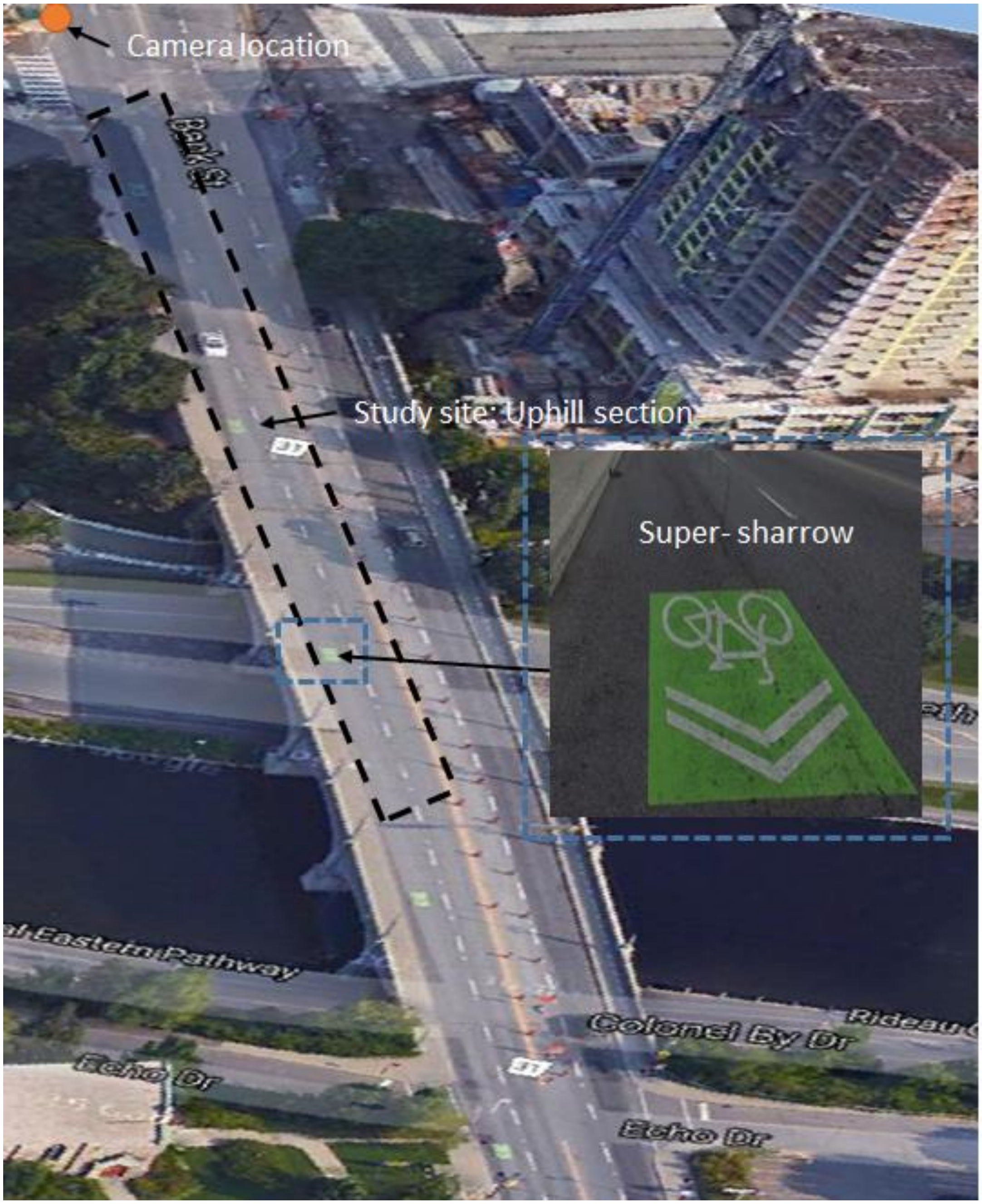


FIGURE 2: Location of the study section and shape of super-sharrows painted (*12)*.

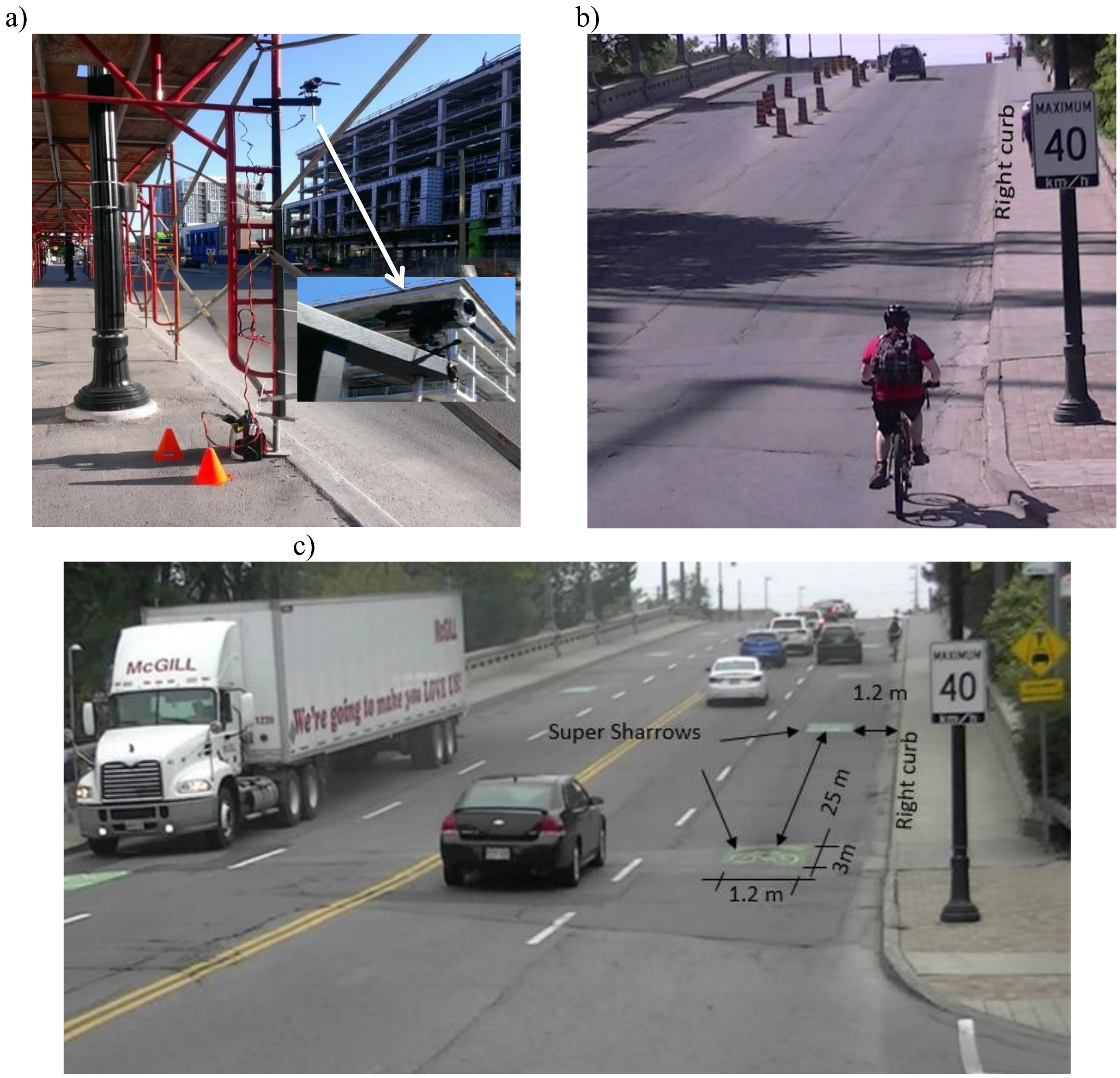


FIGURE 3: Camera position at the site location. (a) video camera set-up. (b) video frame phase 1 (pre-treatment). (c) video frame of phase 4 (post-treatment).

Observed Performance Parameters

Different performance parameters were extracted from the video data collected. A complete list of performance parameters is given below:

1- When a cyclist and a motor vehicle are adjacent, [i] the lateral distance between this cyclist and the adjacent motor vehicle and [ii] the lateral distance between this cyclist and the curb were measured.

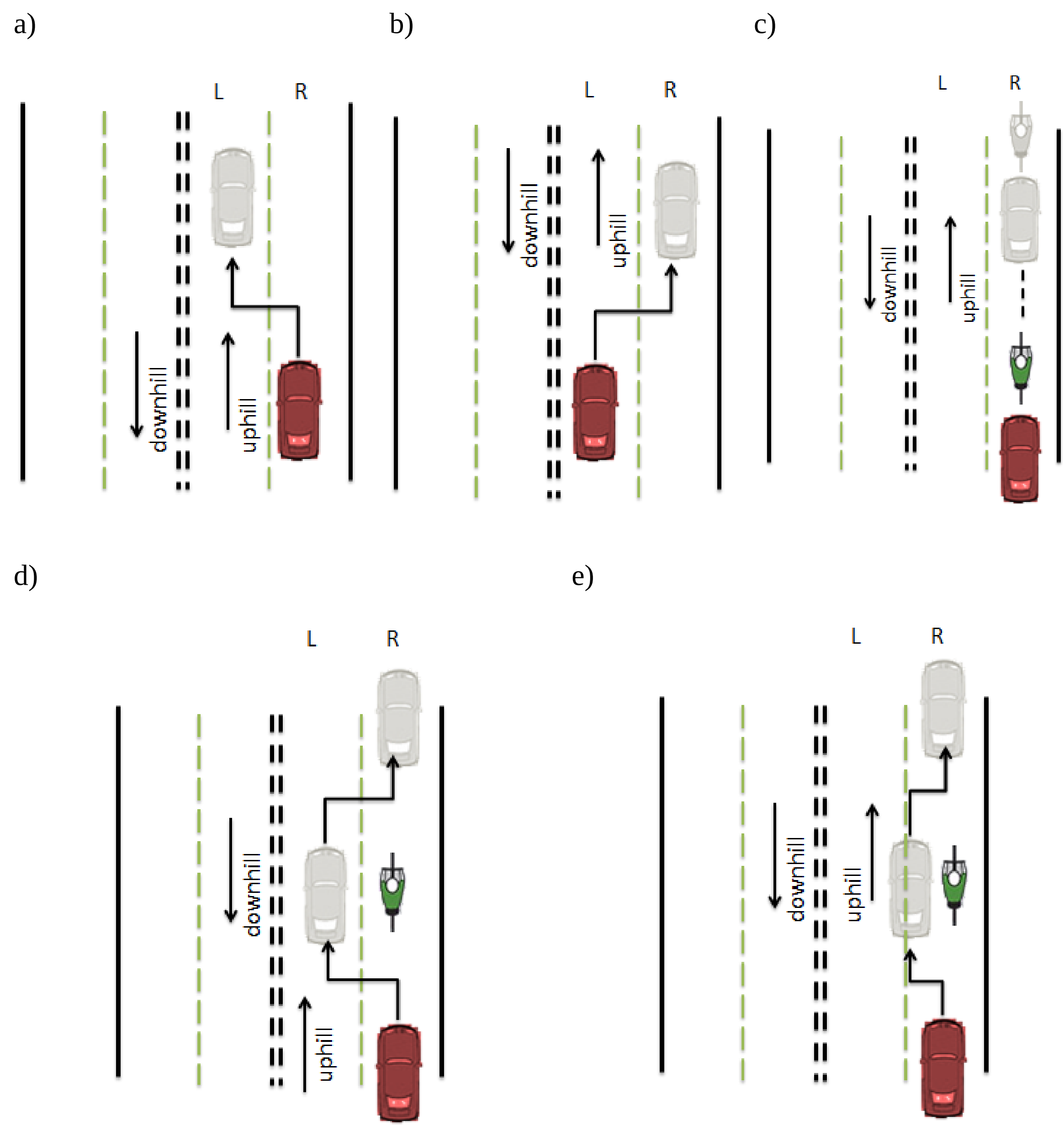
2- Video events containing lane change maneuvers from the right lane to the left lane were identified. Based on the presence of a cyclist immediately in front of the vehicle performing the lane change maneuvers, two subsets of these events were identified: [i] lane change maneuvers in the presence of a cyclist and [ii] lane change maneuvers when a cyclist is not visible in front of the vehicle performing the lane change maneuvers. The lane change maneuver is defined as an event involving the change in the lateral position of a vehicle observed on the curb lane into the left lane where more than half its outline is visible to be within the left lane. Then the rates of the motor vehicle lane change maneuvers were calculated. The rates are calculated as the number of motor vehicles that makes lane change maneuvers out of the total number of motor vehicles in a specific travel lane in pre- and post-treatment conditions.

3- Video events containing lane change maneuvers from the left lane to the right lane were identified. Whenever the motor vehicle made a full lane change maneuver from the left to the right lane (L-R) with/or without presence of an adjacent cyclist in the right lane with full encroachment into the right lane will be separately identified.

4- Video events containing motor vehicles that made a two-step lane change maneuver from the right to left and back to right lane with full encroachment into the left lane (R-L-R) or with partial encroachment to the left lane (R-R), all in presence of a cyclist were identified.

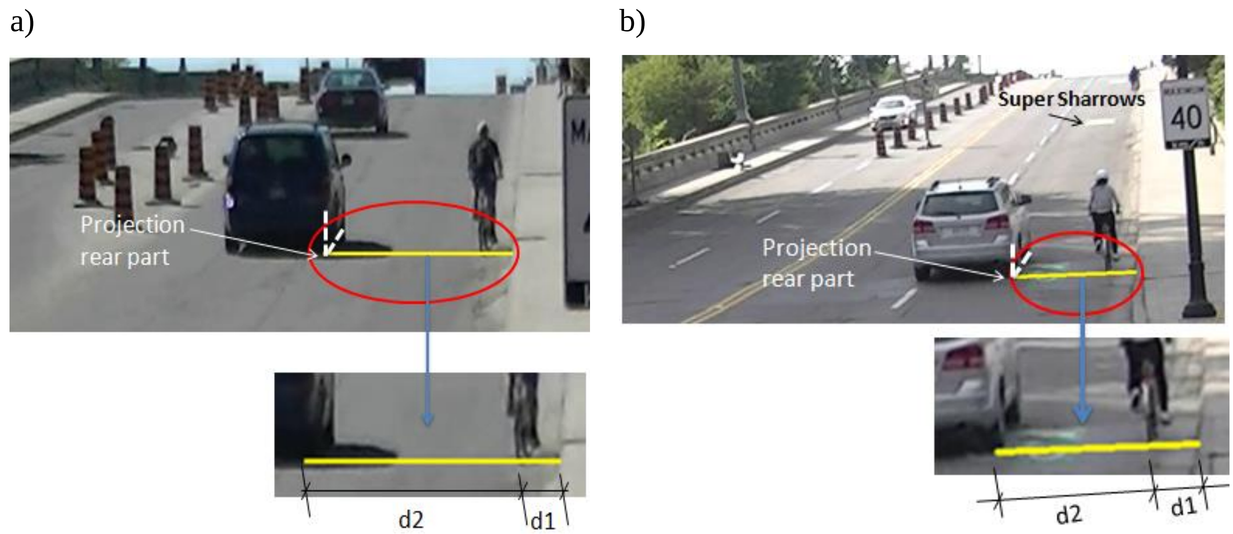
5- In addition, video events containing motor vehicles occupying the curb lane appearing to follow a cyclist who co-occupies the curb lane were identified. The vehicle is considered to follow the cyclist if it is remains behind the cyclist on the curb lane with a similar speed to the cyclist.

6- Count of all cyclists who passed at the location of the middle super-sharrow as shown in Figure 3 (c) within 1.20 m from the curb.



R: curb lane, and L: left lane

FIGURE 4: Motor vehicle lane change maneuvers schematic diagrams. (a) full (R-L) lane change maneuver. (b) full (L-R) lane change maneuver. (c) motor vehicle behind cyclist. (d) full (R-L-R) lane change maneuver. (e) partial (R-R) lane change maneuver.



d1: distance between the right curb and a bicycle.

d2: distance between vehicle and bicycle.

FIGURE 5: Camera video frame explain the lateral distance between a motor vehicle and cyclist, and between cyclist and right curb; (a) phase 1 (pre-treatment), and (b) phase 2 (post-treatment).

ANALYSIS AND RESULTS

Vehicle lane change maneuver analysis

Table 1 shows the summary of the data observation for all 8 days. As shown in Table 1, the effect of the super-sharrows can be investigated through the comparison of pre- and post-treatment maneuver rates. A reduction in the vehicle lane change maneuver can be seen, especially the (L-R) lane change maneuvers, i.e., from left to right lane. Also, the number of (R-L) vehicle lane change maneuvers increased after the super-sharrows were implemented. There was no noticeable change in motor vehicle volumes. Table 2 shows the summary of the data observation for vehicle lane change maneuvers with/or without presence of a cyclist.

As shown in Table 2, in the presence of a cyclist, there is a clear reduction in the number of the motor vehicle lane change maneuvers (R-R) lane. The number of the motor vehicle lane change maneuvers (R-L) lane increased. In addition, the number of the motor vehicle lane change maneuvers (L-R) lane decreased. The changes occurred after the super-sharrows were implemented. These changes were beneficial for the cyclists as it provided them with the required space in the travel lane. This can positively support the stated treatment objectives mentioned in the beginning of this paper.

Chi-square test was conducted to verify the statistical significance of the super-sharrows associated change. The null hypothesis (H_o: treatment has no effect on cyclists and motor vehicle drivers behavior after the treatment was implemented, while the alternative hypothesis (*Ha*: treatment has a positive effect on cyclists and motor vehicle drivers behavior after the treatment was implemented. The Chi-square results are summarized in Table 3 and Table 4. As shown in Table 3, the results were statistically significant ($p < 0.05$) between phase 1 (pre-treatment) and other phases (post-treatment). No significant difference was found between phase 1 and the other phases for the motor vehicle behind cyclist. As well, as shown in Table 4, there was a statistically significant reduction in the number of cyclists who rode on the sidewalk after the super-sharrows were implemented. In addition, a statistically significant increase was found for the number of passages of cyclists ≤ 1.2 m (distance between the edge of the curb and the closest edge of the super-sharrow). These results can also support the treatment objectives positively.

TABLE 1: Summary of the data observation for two conditions.

Conditions	Before	After		
	Phase 1 [1]	Phase 2	Phase 3	Phase 4
Left lane motor vehicle volume[2]	6,039	6,045	6,095	5,613
Right lane motor vehicle volume[2]	2,009	1,928	2,716	2,760
Full L-R lane change maneuver	407	298	307	243
Full R-L lane change maneuver	436	660	605	741
Lane change R-R	228	194	188	165
Motor vehicle behind cyclist	10	14	10	9
Sidewalk bicycle riding	177	106	48	72
Road bicycle riding	558	526	487	463
Number of passages for cyclists ≤ 1.2 m	355	439	403	399

[1] before (pre-treatment) the super-sharrows placed,

[2] two days (approximately 8:00 AM – 5:00 PM) and measured at the beginning of the uphill study section.

TABLE 2: Summary of the motor vehicle lane change maneuvers.

Conditions	Number of motor vehicle lane change maneuvers					
	L-R		R-L		R-R	
	Full[1]	Full	Full	Full	Full	Partial[2]
	Without bike	With bike	Without bike	With bike	With bike	With bike
Phase 1	334	73	274	162	33	195
Phase 2	234	64	442	218	24	170
Phase 3	280	27	441	164	14	174
Phase 4	201	42	475	266	22	143

[1] it means, the whole vehicle body inside the lane

[2] it means, a part of vehicle body outside the lane

TABLE 3: Summary of the statistical analysis: motor vehicle responses.

Lane change maneuvers	Motor vehicle responses							
	With bike (Rate %)				Without bike (Rate %)			
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 1	Phase 2	Phase 3	Phase 4
Full L-R	1.28	1.10[2]	0.46[1]	0.78[1]	5.60	3.91[1,3]	4.61	3.61[1]
Full R-L	40.50	51.22[1,4]	45.72	56.19[1]	17.03	29.46[1,5]	18.91	19.03[1]
R-L-R	8.25	5.64[6]	3.90[1]	4.65[1]				
R-R	48.75	39.95[1,7]	48.51	30.21[1]				
Motor vehicle behind cyclist	2.50	3.28[8]	2.74	2.20				

[1]difference between pre- and post-treatment is statistically significant (<0.05)
[2] Rate = (64/ (6045-234))*100=1.10%
[3] Rate = (234/ (6045-64))*100=3.91%
[4] Rate = (218/ (218+24+170+14))*(6045/6039)*100 = 51.22%
[5] Rate = (442/ (1928-218-24-170-14))*(6045/6039)*100 = 29.46%
[6] Rate = (24/ (218+24+170+14))*(6045/6039)*100 = 5.64%
[7] Rate = (170/ (218+24+170+14))*(6045/6039)*100 = 39.95%
[8] Rate = (14/ (218+170+24+14))*(6039/6045)*100 = 3.28%

TABLE 4: Summary of the statistical analysis: cyclist responses.

	Motor vehicle responses			
	Rate %			
	Phase 1	Phase 2	Phase 3	Phase 4
Sidewalk riding	24.08[1]	16.77[1]	8.97[1]	13.46[1]
Number of passages cyclists ≤ 1.2 m	63.62	83.46[1]	82.75[1]	86.18[1]

[1]difference between pre- and post-treatment is statistically significant (<0.05)

Spacing between cyclists and motor vehicles analysis

An important objective of this measurement is to encourage motor vehicles to following a cyclist along the right lane or otherwise safely overtake. Spacing data was obtained from frames extracted from the video data. In order to measure the spacing, lateral distance between a cyclist and a motor vehicle, the face of the road right curb was used as a reference to relate the positions of a cyclist and a motor vehicle to the geometric and traffic characteristics of the roadway. The observations were taken when a motor vehicle was passing a cyclist and their rear ends were momentarily adjacent to the cyclist.

The lateral distance was calculated manually by identifying and transfer screen coordinate positions to roadway coordinate positions using a special script. These coordinates positions are coordinates of three points along a straight line and identified visually; [i] the projected right rear part of the vehicle on the surface road pavement while making a lane change maneuvers and passing a bicycle as shown in Figure 5, [ii] the bicycle's rear wheel contact point with the road pavement surface, and [iii] face curb point. However, when motor vehicles were completely on the left lane (vehicles further than 3.65 m from the curb) of the road, lateral distance was not calculated. This is done because vehicles are considered not interacting with the cyclist by virtue of occupying a separate lane.

Table 5 summarizes the three lateral distance measurements between right curb, cyclists and motor vehicles for the two conditions pre- and post-treatment and for all phases; [1] the curb face and cyclist, [ii] curb face and motor vehicle, and [iii] cyclist and motor vehicle. As shown in Table 5, there is a noticeable change in the average of the distance between right curb and the cyclist. The average distance increased when comparing pre -treatment to post -treatment. The increase in the average is supportive to the objective (which is to encourage cyclists to ride farther from the curb as the treatment is placed). However, the average distance between the motor vehicle and the cyclist remained similar for all phases (pre- and post- treatment) and most passes are at safe distance to the cyclist (more than 0.91 m) *(11)*.Table 6 shows the lateral distance frequency distribution for the two conditions: pre- and post- treatment of all phases. As shown in Table 6 the highest rate between group lateral distances of phase 1 "pre-treatment" was between 2.0 m and 2.5 m. While the highest rate for the other phases "post-treatment" was found between 1.5 m and 2.0 m. In addition, Table 6 shows that, the high percentage of the motor vehicles passed the cyclist at a safe distance.

TABLE 5: Summary of the three lateral distance measurements between right curb, cyclists and motor vehicles.

Conditions/phases		Distances (m)					
		d	Average	Minimum	Maximum	Std	Total
Before		d1[1]	0.59	0.17	1.50	0.19	
	Phase 1	d2[2]	2.66	1.39	3.65	0.46	183
		d3[3]	2.07	0.89	3.05	0.47	
		d1[1]	0.62	0.23	1.46	0.23	
	Phase 2	d2[2]	2.65	1.58	3.56	0.49	163
		d3[3]	2.03	1.10	3.01	0.44	
		d1[1]	0.64	0.26	1.99	0.26	
After	***Phase 3***	d2[2]	2.66	1.13	3.65	0.51	254
		d3[3]	2.02	0.87	3.17	0.48	
		d1[1]	0.69	0.25	1.65	0.25	
	Phase 4	d2[2]	2.73	1.44	3.65	0.53	165
		d3[3]	2.05	0.74	3.09	0.50	

[1]: distance between the right curb and a cyclist,

[2]: distance between the right curb and a motor vehicle, and

[3]: distance between cyclist and motor vehicle

SYMMARY AND DISCUSSION

Treatments involving pavement markings on roadways, including sharrows, are increasingly important as a means to encourage the safe co-existence of bicycles and motor vehicles by many cities across North America. When it is challenging to install bike lanes, cyclist markings can be useful to help, guide and encourage cycling on roadways. A before and after evaluation was conducted in order to evaluate the impact of shared lane markings, (super-sharrows). In order to assess cyclists and motor vehicles behavior for both conditions, different performance parameters were extracted from the video data collected: [i] lateral distance measurement, and [ii] rates of vehicle lane change maneuvers with/or without cyclist presence.

A total of 2,437 cyclists and 33,205 motor vehicles were observed in both conditions for all phases. The observations were made within a total period of 8 days: two days in pre-treatment and six days in post-treatment conditions. The treatment is the painting of super-sharrows on the curb (right-most) lane of a two-way four-lane undivided urban street in Ottawa, Canada.

TABLE 6: Summary of the lateral distance frequency distribution between motor vehicles to bike rear wheel of the all phases.

Group Lateral Distances "m"	***Before***		***After***					
	Phase 1		***Phase 2***		***Phase 3***		***Phase 4***	
	Observations	Rate %	Observations	Rate %	Observations	Rate %	Observations	Rate %
(0.5 – 1.0]	3	1.64	-	-	3	1.18	3	1.82
(1.0 – 1.5]	22	12.02	21	12.88	33	12.99	17	10.30
(1.5 – 2.0]	47	25.68	64	39.26	95	58.28	63	38.18
(2.0 – 2.5]	78	42.62	49	30.06	81	49.69	48	29.09
(2.5 – 3.0]	31	16.94	28	17.18	36	22.09	29	17.58
(3.0 – 3.65]*	2	1.09	1	0.61	6	3.68	5	3.03
Total	183		163		254		165	

*lane width equal 3.65 meter

Different vehicle lane change maneuvers were observed in this study: [i] motor vehicles that made a full lane change maneuver from the left to the right lane (L-R) with/or without presence of an adjacent cyclist, [ii] motor vehicles that made a full lane change maneuver from the right to the left lane (R-L) with/or without presence of a cyclist in front of this motor vehicle, [iii] motor vehicles that made a two-step lane change maneuver from the right to left and back to right lane with full encroachment into the left lane (R-L-R) or with partial encroachment to the left lane (R-R), all in presence of a cyclist, [iv] motor vehicles that followed the cyclist who co-occupied the right lane.

The results presented in Table 2, showed that there was a variety of changes in the number of motor vehicle lane change maneuvers. Results proved that the treatment achieve the initial purpose of this experiment. There is a clear reduction in the number of the motor vehicle lane change maneuvers (R-R) lane in both full and partial encroachment into the left lane. The number of the motor vehicle lane change maneuvers (R-L) lane increased. In addition, the number of the motor vehicle lane change maneuvers (L-R) lane decreased. These changes were beneficial for the cyclists as it provided them with the required space in the travel lane.

In addition, Chi-square test was used to test the statistical significance of the difference in the motor vehicle lane change maneuvers. For a majority, the results were statistically significant ($p < 0.05$) between phase 1 (pre –treatment) and the other phases (post –treatment) in having a positive effect on cyclists and motor vehicle drivers' behavior after the treatment was implemented.

Three different lateral distance measurements were calculated for both conditions; [1] the right curb edge and bicycle, [ii] curb edge and motor vehicle, and [iii] bicycle and motor vehicle. The results showed that the average distance between cyclists and the right curb increased between the phases of post –treatment and pre –treatment. As well, the treatment was effective in discouraging cyclists to ride on the side walk.

Although the difference in the average lateral distance between the pre- and post-treatment conditions slightly increased, the results showed no statistical significance between the all averages in all lateral distance measurements. A statistically significant increase was found for the number of passages of cyclists ≤ 1.2 m (distance between the edge of the curb and the closest edge of the super-sharrow). This indicates that regardless of the presence of an adjacent vehicle, cyclists appear to have moved closer to the vicinity of the curb edge with the presence of the super-sharrows. This conclusion however was not supported when isolating cyclists at the moment they are adjacent to vehicles, in which case the distance between the cyclist and the curb on average did not change.

CONCLUSIONS

This paper examined the change in operational and safety measures for cyclists and motor vehicles associated with the painting of super-sharrows on the right lane of a two-lane one-way road section. The key findings were as follows:

- Super-sharrows had an effect on motor vehicle lane change maneuvers, which increased the percentage of motor vehicles that changed from R-L lane (right to left) with the presence of a cyclist on the right lane.
- The number of motor vehicles that changed from R-R lane (right to right) in both full and partial encroachment into the left lane decreased. As well, the number of the motor vehicle lane change maneuvers L-R lane (left to right) decreased.
- The average distance between the motor vehicle and the cyclists (passing distance) remained the same between all phases and overall exceeds the safe clearance between a cyclist and an adjacent vehicle. This finding indicated that this average distance was unaffected by the treatment.
- Cyclists were found to be riding further from the right curb with the presence of the super-sharrows.
- Fewer cyclists were observed riding on the sidewalk, with the presence of the super-sharrows.

These findings indicate a positive trend in both cyclist and motor vehicle driver behavior with the presence of super-sharrows. As well, the pedestrians' environment improved when cyclists did not ride on the side walk.

For future research and recommendations, some concerns that may be considered are; [i] the presented methodology offer the potential and flexibility to be expanded to consider other marking applications (side-by-side with/or without street parking, and conflict zones applications), [ii] the statistical analysis was conducted to investigate the impact of performance measures on operational and safety measures for cyclists and motor vehicles and the results provide useful information into the consideration required for the design of cyclist facilities, [iii] passing motor vehicle speed can be used as an additional performance measure in order to assess the motor vehicle behaviors in pre- and post-treatment conditions, [iv] in order to evaluate the reaction of the motor vehicle drivers to whether/or not they responded to the treatment, different sites with one direction travel lane should be tested with the same treatment to make sure that the objective of the treatment worked, and finally [v] user surveys can give more insight into the interpretation and concerns of road users experienced at the personal level.

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