Impact of Bicycle Boxes on Safety of Cyclists: a Case Study in Montreal

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ABSTRACT

This paper presents a methodology to evaluate the effectiveness of a bicycle treatment (bike boxes) at intersections using a before-after surrogate safety analysis based on longitudinal video-data analysis. As a surrogate safety measure, cyclists' red-light violations are quantified for two periods before and two periods after the installation of a bicycle box at a signalized intersection in Montreal. For this purpose several hours of video were collected before and after the installation of the treatment. Based on the video data, red-light violations and potentially associated factors were collected for each cyclist that crossed the intersection, such as sex, age, group size, use of helmet, whether a cyclist stopped before crossing, vehicle-cyclist gap, etc. Violations with a short vehicle-cyclist gap were classified as dangerous (i.e., those situations in which cyclists pass the intersection during the red phase with a small vehicle gap). For the data analysis, a multinomial logit regression technique was used to identify the factors that increase or decrease the probability of cyclist violations as well as their changes over time. Both raw estimates and model estimates show that the presence of a bicycle box has a significant impact on the total number of cyclists' violations; however, the impact on the number of dangerous violations is not clear. More video data from other intersections before and after the treatment implementation is required to validate these preliminary conclusions. Moreover, the video-data generation and surrogate approach proposed here can be applied to the evaluation of other bicycle treatments.

INTRODUCTION

As urban cycling gains momentum, safety concerns for cyclists increase for governments and society in North American cities. Considering the fact that bicycling fatalities in North America, especially in United States, are 11 times higher than car commuter fatalities per km traveled *(1)*, cyclist safety should be an important concern when encouraging active transportation in a city.

To improve cyclist safety at intersections, different engineering countermeasures have been recommended, such as the installation of bicycle boxes, which are also known as Advanced Stop Box (ASB). Although they have been used for over 20 years in many Northern European countries and in the United Kingdom, only a few cities have implemented this kind of treatment in North America *(2)* (e.g., Portland, Vancouver, Ottawa and recently Montreal). At intersections with bicycle boxes, cyclists have a legal way to bypass the first stop line and place themselves in front of motor vehicles at red signal phase. Among the advantages of bicycle boxes in the literature, one can mention the improvement of driver awareness of cyclists, the increase of cyclists' comfort, the decrease in cyclists exposure to direct exhaust of vehicles, the reduction of conflicts between cyclists and motor vehicles, etc. *(3)*

Despite the increasing popularity of this treatment, very little research has been done about its effectiveness in the North America context. To our knowledge, no traditional safety studies based on historical crash data are available. This can be associated to several reasons, including the lack of data such as history of cyclist-vehicle crashes and their characteristics and bicycle volumes before and after the installation. Also, a general shortcoming of the traditional before-after studies is the need to wait for crashes to happen for several years before and after the installation and at control group sites. Implementation of traditional before-after studies can take a long time and demand resources. Moreover, effectiveness over time can change due to road user adaptation. Longitudinal traditional safety studies would demand even more years of data, which makes them infeasible.

In these conditions, surrogate safety analyses can be used instead of the traditional crash-based approaches. It can be argued in addition that surrogate safety analysis is more suitable since it will allow for quicker evaluation of the treatment and adjustment if its performance is not satisfying. Despite the growing literature, very few studies have investigated the impact of bicycle boxes using before-after video data and surrogate measures in North America. Among the few studies, we can mention the recent study by Dill et al. *(2)*. Using a before-after surrogate safety approach, this study relied on the observation of cyclist-vehicle conflicts before and after the introduction of the treatment at 10 intersections. For each location and time period (before and after) videos were recorded during two peak-period hours and one off-peak hour for 6 hours in total. This study found a reduction in the proportion of cyclists entering pedestrian crosswalks from 40.9 % to 24.9 % and from 22.7 % to 12.5 % for colored and uncoloured bike boxes respectively. Another important study on bicycle boxes is the one by Loskorn et al. *(4)*, studying two intersections in Austin, Texas: assuming that the correct use of facilities translated into safe road user crossings, they found that the safety of cyclists and motorists improved significantly after the installation of bicycle boxes.

Despite these studies, research gaps still exist. Few studies have looked at the adaptation of cyclist behaviour over time using longitudinal data. As demonstrated in other studies (e.g. see *(5)*), the effectiveness of a treatment can vary over time because of adaption. Therefore, there is a need to look at the changes in cyclist behaviour in the short, medium and long-term after the implementation of a countermeasure. Also, past studies have looked at the typical benefits of bicycle boxes such as the reduction of motor vehicle-cyclist conflicts and the comfort of cyclists. To our knowledge no study has dealt with the impact of bicycle boxes in terms of red-light violations. It could be hypothesized that by increasing the comfort and allowing cyclists to wait in front of vehicles in a designated space, more cyclists are willing to stop and wait for the green light. In other words, improving cyclists' comfort may lead them to adopt safer behaviours by decreasing the proportion of cyclist violations.

Accordingly, the main objective of this work is to introduce a video-based methodology to study cyclist behaviour before and after the introduction of a bicycle treatment (bike boxes) in a signalized intersection, over the short and medium term. The main behavioural parameters of interest are red-light violations in general and dangerous red-light violations in particular. Other behavioural parameters such as stopping location are also investigated. For this study, longitudinal video data is collected on four occasions, two before and two after the installation of the treatment.

The background of this work is presented in the next section. It is followed by a description of the proposed methodology and data collection process, which is then applied to a dataset collected at Montreal. Finally, the paper is concluded and future work is discussed.

BACKGROUND

In recent years, cyclist safety issues have attracted a lot of attention. Several recent studies have tried to document the factors associated with cyclist injury risk, in particular the factors of the road and built environment *(6)*. A particular subject of interest is the identification of engineering treatments (countermeasures), such as bicycle boxes, which can improve safety at signalized intersections.

Despite the importance of this treatment, few studies have looked at the safety effectiveness of bicycle boxes at intersections in US and Canadian cities, where its popularity is increasing. Among the very few studies, one of the first studies on bicycle boxes was carried out in Oregon in 1998 at a busy downtown intersection with two one-way streets. In his study *(7)*, Hunter used video recorded before and after the installation of the bike box to observe cyclist behaviour and conflicts with vehicles, other bicyclists and pedestrians. In addition to these data, other information was collected through short oral surveys. Statistical tests were done using chi-square and showed no significant improvement in the total number of violations and conflicts. The author suggests that this result could have been due to a high percentage of encroachment of vehicles into the bike box.

In the recent work of Dill et al. *(2)*, the behaviour of motorized vehicles and cyclists and vehicle-cyclists conflicts were analyzed using video data before and after the installations of bike boxes at 10 signalized intersection in Portland, Oregon. A high rate of compliance and understanding of the markings was found in both video data and survey of motorists. The number of conflicts decreased, while the total number of cyclists and motor vehicles turning right in the intersections increased. Also, in terms of perceived safety, over three-quarters of the cyclists that participated in the survey thought that the boxes made the intersection safer.

Loskorn et al. *(4)* researched the impact of bicycle boxes and the color of the boxes on the safety of cyclists. For this purpose they used video footage of two intersections in Austin, Texas for three periods of time: before the installation of the bike boxes, after marking the bike boxes and after adding color to the bicycle boxes. In this study the main criteria for safety was the correct usage of facilities, assuming that if bicyclists use the facility correctly and without conflicts, they are behaving in a safe way. The results of this study showed bike boxes can improve the safety of both cyclists and motorists at intersections. On the other hand, they showed that adding color to the bike box did not significantly increase the percentage of cyclists that used the bike box, but it did make motorists more aware of the presence of bicyclists and increased the percentage of cyclists that used the bicycle lane and stopped behind the stop line. As the authors mentioned in their paper, cyclists not using the facility correctly are not necessarily behaving dangerously.

It is important to mention that several studies have been published in recent years related to surrogate analysis of pedestrian safety. Surrogate analysis techniques and video data with various levels of automation have been extensively used in pedestrian- vehicle conflict studies *(8)(9)*. Although tracking and classifying all road users is not yet feasible in dense and mixed outdoor environments with varied movements, this can be achieved in specific settings *(9)*. Surrogate measures of safety can then be automatically computed such as TTC (Time to Collision), PET (Post Encroachment Time), Gap Time, and DST (Deceleration to Safety Time) to estimate the safety of pedestrian-vehicle conflicts.

The recent study of Brosseau et al. *(10)* investigated the impact of different variables on pedestrians' violation of traffic lights and dangerous crossing situations at signalized intersections. After analyzing data from seven intersections with similar geometry in Montreal, several variables were determined to have an influence on violations and dangerous crossings such as age, sex, group size, conflicting vehicle flow, presence of pedestrian signal as well as maximum waiting time (red phase) and intersection clearing time. From the above variables it is not possible to change age, sex and group size, but by reducing the maximum waiting time or installing the pedestrian's signal at intersections, it is expected that the number of violations and dangerous crossings would be reduced.

METHODOLOGY

The proposed approach consists of three steps:

1. Site selection
2. Video data collection and processing
3. Data analysis and interpretation: using logistic regression techniques

Site Selection

The first intersection where a bicycle box was installed in Montreal, Canada, at Milton St. and University St., is the object of this study. This intersection has four legs with two bicycle facilities connecting downtown Montreal. On the main approach (on University Street), a cycle-track was installed 2 years before the installation of the bike box. On Milton St., a bicycle lane flowing in the opposite direction of motorized traffic was installed several years ago. Thousands of cyclists pass through this intersection during the biking season (summer), with an average daily flow of about 3000 cyclists. The two streets are unidirectional. See Figure 1 for details.

Figure 1: *Bicycle box on Milton St., Montréal*

Data Collection and Processing

A mobile video-camera system developed by the transportation research group at McGill was used to record elevated video data *(11)*. This system is discreet and easy to install along existing posts. Cyclist and driver behaviour is therefore not affected by the video camera presence. Several hours or days of video can be taken without the need for a permanent installation as it is power independent. This system was also used by the research team in previous studies *(10)(12)*.For this study, several hours of video were taken before and after the installation, all of them in weekdays.

- Before the installation:
  - 213 minutes, before the installation in May 2011
  - 88 minutes, before the installation in August 2011
- After the installation:

- 160 minutes, just after the installation in September 2011
- 172 minutes, around ten months later in June 2012

The weather conditions were very similar during the hours in the before and after periods and all the video collection was done between 12pm and 5pm. After data collection, video was processed manually with the help of a MATLAB GUI (Graphic User Interface) to reduce the error and increase the speed and comfort of data generation *(13)*.

Two surrogate safety measures are used in this study: i) the cyclist red-light violations and ii) Post-Encroachment Time (PET) *(14)*, which is the time between the departure of the encroaching cyclist from the conflict point and the arrival of the first vehicle at the conflict point at the intersection. Based on the PET, red violations are classified into two categories:

- "Safe" violations: cyclists pass the intersection during the red phase with sufficient safety margins (PET ≥ 5seconds).
- Dangerous violation: cyclists pass the intersection during the red phase with a small PET (PET < 5 seconds).

In addition, the following information was collected for each individual cyclist who passed the intersection approach where the bike box is located (from Rue Milton to University St. or McGill entrance). These variables include:

- Cyclist gender
- Age group (an approximate measure of the age obtained by observation)
  - Very Young (Under 18)
  - Young Adult (18 to 35)
  - Middle Age (35 to 60)
  - Old (Over 60)
- Arrival pattern: single or group arrival
- Helmet use: Whether the cyclist wore a helmet

If the cyclist arrives to the intersection on the red phase, some additional information was collected related to violation and stopping behaviour:

- Red-light decisions: whether the cyclist
  - Respected the light
  - Passed the pedestrian light
  - Passed the red light
- Stopping behaviour before crossing: whether the cyclist
  - Stopped before crossing
  - Slowed down before crossing
  - Passed the intersection without stopping
- Stopping location: if the cyclist stopped before crossing the intersection during the red phase, one additional variable was collected:
  - Right place (behind the stop line before the installation period and in the bike box after the installation of bike box)
  - Wrong place (in front of the stop line before the installation and out of the bike box after the installation)
- PET: If cyclist did not respect the light then PET was calculated. Based on the PET measure, violations were classified in dangerous violation and "safe" violation

It is important to note that very few cyclists (less than 2 %) respect the pedestrian light and stopped for it. Since we are mostly interested in cyclist safety, we decided to focus on bike-vehicle interactions and the corresponding violations that may lead to bike-vehicle collisions. Cyclists passing during the pedestrian green light were therefore not recorded as violations.

Data analysis and interpretation:

In order to identify the factors that influence the two outcomes of interest and the magnitude of their effects, binary and multinomial logistic (MNL) regression techniques were used. The three analyses of interest are:

1- Violation represented by a binary variable and modeled using a binary logit regression
2- Dangerous violation represented also by a binary variable and modeled by a binary logit regression
3- General cyclist decision: dangerous violation, "safe" violation and no violation represented by a multinomial logit regression model *(15)*

The most important component of an MNL model is the definition of its utility functions for the choices (1).

$$U_i = \beta_{i,0} + \beta_{i,1}x_1 + \beta_{i,2}x_2 + \cdots + \beta_{i,n}x_n + \varepsilon_i \qquad 1 \le i \le m \qquad (1)$$

Here, *m* is the number of alternatives and *n* is the number of possible independent variables. U_i are utility functions of different alternatives, $\beta_{i,j}$ are coefficients of variables, x_k are the independent variables and ε_i is the error of each term which is assumed to follow a gumbel distribution. In a MNL model, the $\beta_{i,j}$ are unknown coefficients that must be found to optimize the maximum likelihood. In the current study, we used an open source software designed for the estimation of discrete choice models called BIOGEME *(16)(17)*. The final probabilities of different alternatives are computed from the following equation (2):

$$P_i = \frac{\exp(U_i)}{\sum_{\forall j}\exp(U_j)} \qquad (2)$$

Note that a binary logit model is a simple form of a multinomial logit model with only two alternatives. For more detailed explanations of the MNL model, the readers are referred to *(15)*.

RESULTS

Exploratory Analysis

A summary of the data extracted from the video observations is presented in **Table 1**. From this table, several observations can be made. The total number of cyclists arriving during the four periods of video recording is 1224, from which about 70 % (851 cyclists) arrived on the red phase. From these, 60 % did not respect the red light (note that we did not consider cyclists who passed the pedestrian light as a violation).

The gender distribution of the cyclists in our four periods of data gathering remains almost the same, with a proportion of around 63 % male to 37 % female. More than 90 % of cyclists who passed the intersection were estimated to be young adults (between 18 to 35 years old). This high density of young cyclists is due to the location of the intersection at the entrance gate of McGill University.

At first glance, the safety of cyclists could be presented by the following measures: the proportion of cyclists stopping before crossing, stopping in the right place (proper use of bicycle box), the proportion of violations, and the proportion of dangerous violations. In Table 1, the changes in behaviours of cyclists for the mentioned characteristics are shown (note that these percentages are only for the cyclists who arrived on the red light and had a decision to make: pass the red light or wait for the green light). From these raw observations, it seems that the bike box has a positive effect on safety of cyclists but that this impact has slightly diminished over time. For instance, the proportion of violations has decreased after installation of the bike box in 2011 but then slightly increased in 2012. It is difficult to draw conclusions for the other behaviours as they do not exhibit clear trends before and after the installation.

Table 1. Summary of data for the before and after study

Variable group	Variable	Before installation (May 2011)	Before installation (August 2011)	After installation (September 2011)	After installation (June 2012)
General cyclist characteristics	Total number of bicyclists	346	133	404	341
	% of male	62.4 %	63.9 %	62.4 %	62.5 %
	% of young adult	90.8 %	91.7 %	97.3 %	92.4 %
	% of group arrival	53.2 %	45.9 %	51.2 %	47.8 %
	% of helmet use	34.4 %	31.6 %	33.9 %	39.6 %
Behavioural outcomes	Total number of bicyclists arriving on red	239	95	287	230
	% of bicyclists stopped before crossing (from cyclists arriving on red)	71.6 %	61.1 %	69.0 %	66.1 %
	% of bicyclists stopped in correct place (from cyclists arriving on red)	28.0 %	21.1 %	31.4 %	30.4 %
	% of violation (from cyclists arriving on red)	66.1 %	68.4 %	54.7 %	57.0 %
	% of dangerous violation (from cyclists arriving on red)	10.5 %	6.3 %	6.3 %	7.8 %

Binary Logit Model for General Violation and for Dangerous Violation:

The next step is to carry out a regression analysis. To estimate multinomial regression parameters, the specialized software BIOGEME was used. In each regression analysis, all the variables collected for each cyclist who arrived on the red light was tested to find the best parameters for modeling. No violation and the set of "safe" violations and no violations are the base alternatives (all of their coefficients are set to be zero) respectively for the first model (general violations) and the second model (dangerous violations). Note that only variables with significant effects are used in the models and presented in the tables (except variables related to the presence of bicycle box which are used in all models to see their effects), but all the variables and their different combinations were tested to obtain the best model with the highest likelihood. The final results for the two models are shown in the Tables 2 and 3 respectively.

As initially suspected, being a young adult significantly increases the probability of general violations. Also, helmet usage has a negative impact on the probability of general violation. This might be associated to the fact that cautious cyclists with more appropriate behaviours are those that wear helmets. In other words, the helmet usage (which is not mandatory) can be seen as a proxy for risk taking. Other variables associated to the probability of red light violation are stopping before crossing and stopping in the right place, which both have negative effects.

From the first model (general violations), one can see that the bicycle box has a significant impact on reducing the probability of violations, but the magnitude of this influence is greater for the first period of observations just after the installation of the bicycle box. According to the elasticity, the reduction of general violation is about 14.5 % in the first after period and 11.7 % in the second after period, while controlling the other variables. This is consistent with the raw numbers previously presented.

Unlike the modeling for general violations, the presence of bicycle box does not have a significant effect on the proportion of dangerous violations.

Table 2. Model outcome of all violations vs. no-violation

Explanatory variables	**Violation**		
	Coefficient	**p-value**	**Elasticity**
Constant	1.31	0.00	-
Young Adult	0.936	0.00	14.8 %
Wear Helmet	-0.615	0.00	-15.3 %
Stop Before Crossing	-1.29	0.00	-35.9 %
Stop in Right Place Before Crossing	-0.884	0.00	-23.2 %
Presence of Bicycle Box in 2011	-0.586	0.00	-14.5 %
Presence of Bicycle Box in 2012	-0.485	0.01	-11.7 %
Number of cases	851		
Log likelihood at convergence	-495.428		
Log likelihood for constants-only model	-572.570		
Rho^2	0.160		
Adjusted Rho^2	0.148		

Table 3. Model outcome of dangerous violation vs. other situations

Explanatory variables	**Dangerous Violation**		
	Coefficient	**p-value**	**Elasticity**
Constant	-1.29	0.00	-
Male	0.751	0.02	70.6 %
Stop in Right Place Before Crossing	-2.02	0.01	-83.7 %
Stop Before Crossing	-1.94	0.00	-82.4 %
Slow Before Crossing	-1.49	0.00	-72.9 %
Presence of Bicycle Box in 2011	-0.320	0.33	-22.8 %
Presence of Bicycle Box in 2012	0.0715	0.21	5.7 %
Number of cases	851		
Log likelihood at convergence	-193.460		
Log likelihood for constants-only model	-234.586		
Rho^2	0.672		
Adjusted Rho^2	0.660		

Multinomial Logit Model for Dangerous Violations and “Safe” Violations:

In the last model, two types of violations are considered separately and are compared to no-violation. Results are presented in table 4.

Table 4. Model outcome for MNL model of dangerous violation and “safe” violation vs. no-violation

Explanatory variables	“Safe” Violation of Light			Dangerous Violation of Light		
	Parameter	p-value	Elasticity	Parameter	p-value	Elasticity
Constant	1.88	0.00	-	0.170	0.66	-
Male	-	-	-	0.838	0.01	96.3 %
Wear Helmet	-0.533	0.00	-15.0 %	-1.14	0.00	-64.8 %
Stop Before Crossing	-1.16	0.00	-35.4 %	-2.02	0.00	-85.0 %
Stop in Right Place Before Crossing	-0.784	0.00	-22.9 %	-2.37	0.00	-89.3 %
Presence of Bicycle Box in 2011	-0.500	0.01	-14.0 %	-0.690	0.05	-46.2 %
Presence of Bicycle Box in 2012	-0.444	0.02	-12.3 %	-0.545	0.13	-38.5 %
Number of cases	851					
Log likelihood at convergence	-679.387					
Log likelihood for constants-only model	-771.095					
Rho2	0.273					
Adjusted Rho2	0.259					

Here, no-violation is considered to be the base alternative and all of its coefficients are set to be zero. Considering the almost the same parameters founded for the third model, this model supports the results of the two previous models. However, in this third model, unlike the second model (modeling for dangerous violation), the bike box in 2011 has a significant effect on dangerous violations. Further discussions will be presented in the following section.

Discussion

Due to proximity of the studied bicycle box to the McGill University, one can argue that the high density of young adults in the dataset could make the results hard to generalize to other intersections and locations of the city. Nevertheless the modeling results in the previous sections showed that several variables can have an impact on the decision of cyclists to respect the light or not. Age, gender, wearing a helmet, stopping before crossing, stopping in the right place and the presence of a bicycle box have the most important influence on whether cyclists violate the red light. It should be mentioned that it is not possible to use and change all of these variables to improve safety and reduce the share of violations. For instance, we cannot change the age of cyclists, but it is possible to force cyclists to wear helmets, and it may be that wearing a helmet has a more or less conscious effect that increases cyclist awareness of crash risks at intersections.

The results showed that the installation of this bicycle box in Montreal significantly reduced cyclist violations. However, because of inconsistent results from the second and third models, the effect of the aforementioned bicycle box is not completely clear. This is due to the limited number of observations for dangerous violation in the data set. Further conclusions must be made after additional data collection. Based on the current dataset and the variables with a significant impact on dangerous violations (in both second and third model), the only variables that can be controlled to some degree are the share of cyclists stopping before crossing and the share of cyclists stopping in the right place before crossing the intersection, which could be increased for example through education and enforcement to improve safety. Furthermore, even though the effect of the bicycle boxes decreased between the two “after” periods, a reduction in cyclist violations was still observed. Therefore, installation of more bicycle boxes at intersections with a high density of cyclists could be an effective way to improve cyclist safety.

CONCLUSION

This study presented a statistical method using surrogate safety measurements to investigate the effect of bicycle boxes on safety of cyclists at intersections. As a case study, the first installed bicycle box in Montreal was chosen and video data was recorded for two periods before the installation and two periods after the installation of the bike box. Data extraction from the recorded video was done manually and statistical analysis was done using binary and multinomial logit models.

From the almost consistent results of three discrete choice models, it can be concluded that although the effect of the studied bicycle box in Montreal is not completely clear, it significantly reduced the total number of violations. For a better assessment of the impact of bicycle boxes on the safety of cyclists, more data is needed, as only 67 dangerous violations (less than 8 % of dataset) were observed in the whole dataset. The only strong conclusion is that the installed bicycle box in Montreal significantly reduced the total number of cyclist violations. Finally, the magnitude of the reduction in cyclist violations decreased between the two “after” periods, suggesting that effect of bicycle boxes may decrease over time as cyclists grow accustomed to the new infrastructure.

In our future work, we will use an automatic video analysis tool, which was presented in *(8)*, to collect data from the recorded videos. Currently the main hurdle is that it cannot distinguish bicycles from vehicles. With further development, it will be possible to collect data automatically in order to reduce the error caused by manual data extraction and to increase the speed of data collection. In addition, two more bicycle boxes will be installed in Montreal; in our future work we will add their before-after study data to the current dataset in order to have more general results. Also, greater attention will be paid to how cyclists interact with pedestrians and pedestrian signals.

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