Impact of Curb Radius Reduction on Pedestrian Safety: A Before-After Surrogate Safety Study in Toronto

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Abstract

Large curb radii at intersection corners increase drive sight angle, reduce pedestrian visibility, and contribute to high-speed turning movements. These factors can lead to uncomfortable and dangerous interactions and potentially collisions with pedestrians. Some ways to increase the safety of pedestrians at intersections is to reduce turning vehicle speeds as well as to reduce crossing distance for pedestrians. This can be achieved through adjustment to the intersection curb radius. These treatments have increased in popularity in Canadian cities like City of Toronto; however, very little is quantified about their effectiveness. This is in part due to the fact that before-after studies to evaluate the effectiveness of curb radius adjustment, or any other treatment, can take long time given the low collision frequency. This paper applies a surrogate safety approach to evaluate the effectiveness of curb radii reduction in terms of reducing the speed of turning vehicles as they interact with pedestrians, and reducing the frequency and severity of conflicts between turning vehicles and pedestrians at the studied intersection. Using 72 hours of video from before and after the curb radius adjustment at the signalized intersection of Davenport Rd & Christie St, it was found that this treatment has positive effects on pedestrian safety.

INTRODUCTION

In an effort to improve pedestrian safety, the City of Toronto has been implementing geometric modification at various intersections. Davenport & Christie and Yorkwoods & Driftwood are intersections were selected for modification following complaints from the public and staff observation of vehicles speeding through the turns, not yielding, and not stopping at the stop signs or red lights. In addition, in the past 5 years, one of the intersections experienced two pedestrian-vehicle collisions which resulted in serious injuries.

The geometric safety improvement chosen for the signalized intersection of Davenport & Christie was curb radius reduction. This paper presents the results of the surrogate before-after safety study that evaluates the effectiveness of the curb radius reduction at the north-west corner of Davenport & Christie. Video data from before and after the curb radius reduction was collected, analyzed, and evaluated using the key indicators of vehicle turning speed and vehicle-pedestrian

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conflict. A similar approach will be used to study the effect of the curb modification at the Yorkwoods & Driftwood intersection, which is planned for 2017.

There are several benefits for vehicles and pedestrians when oversized curb radii are reduced. These include reduced pedestrian crossing distances, reduced vehicle turning speeds, improved driver sight angle and increased pedestrian storage space. These benefits have been referenced in the TAC Geometric Design Guide for Canadian Roads [1], NACTO Urban Streets Design Guide [2] and Complete Streets guidelines of several North American jurisdictions such as Boston [3], Chicago [4] and Toronto [5], to name just a few.

The objective of this paper is to evaluate the effectiveness of curb radii reduction at the signalized intersection of Davenport & Christie in terms of reducing the speed of turning vehicles as they interact with pedestrians, and reducing the frequency and severity of conflicts between turning vehicles and pedestrians.

This project was completed for the City of Toronto by Brisk Synergies Tech Corp in collaboration with Ontario Traffic Inc. (OTI). OTI was in charge of camera installation and video recording, and Brisk Synergies Tech Corp carried out the video data generation and analysis and prepared this paper.

METHODOLOGY

Surrogate road safety evaluation is an emerging but recognized approach for safety analysis. This approach can be used to evaluate treatment effectiveness without waiting years to observe potential collisions. Examples of using surrogate measures for safety studies can be found in [6-9]. Two common surrogate safety indicators are used in this paper: traffic speed and vehicle-pedestrian conflicts. Using video data collected before and after the treatment, these two indicators are measured to determine the safety effectiveness of curb radius reduction at the study intersection. An earlier implementation of the surrogate safety methodology used in this study has been documented in [8] and [10].

Safety Measures

For conflict analysis, the main surrogate safety measure considered in this study is Post Encroachment Time (PET) between a pedestrian and a vehicle (Fig. 1). Note that PET can be computed for any pair of road users.

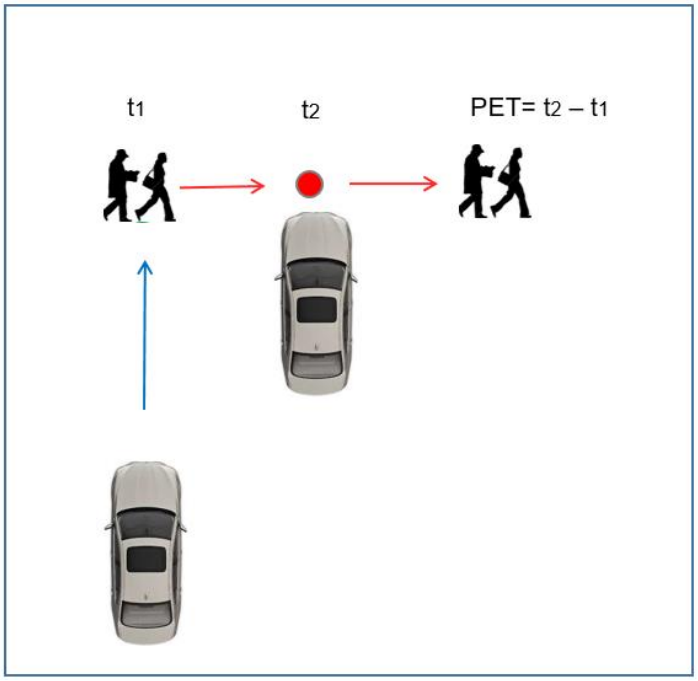


Figure 1. Post Encroachment Time

PET is defined as the time between the first road user leaving the common spatial zone (where two road users could potentially collide) and the second road user arriving to the common spatial zone [11]. In other words, the PET value determines how close, in time, the two objects were to colliding. The lower the PET, the more dangerous the conflict.

Vehicle speed is also considered as a measure of safety in this study. In particular, the speed of vehicles interacting with pedestrians is of interest. For this analysis, measurement of the vehicle speed is separated for those interactions in which the observed PET was less than or equal to 3 seconds, and those in which the observed PET was greater than 3 seconds.

Study Site and Traffic Video Data

To investigate the safety problems at the intersection of Davenport & Christie, traffic videos were recorded from 7:00 am to 7:00 pm on August 2nd, 3rd, and 4th 2016 (before the curb radius reduction) and from 7:00 am to 7:00 pm on November 8th, 9th, and 10th 2016 (after the curb radius reduction). Video recordings were analyzed with an improved and extended version of the algorithm introduced in [10]. The results of the processing and analysis for the 72 total hours of video are included in this paper. Two screenshots showing the conflict scenario and the geometry of the studied intersection before and after the curb radius adjustment are presented in Fig. 2.

Figure 2. Conflict scenario of a vehicle turning and a pedestrian crossing, at the Intersection of Davenport & Christie before (left) and after (right) radius adjustments

Video recordings for the before study have a 720p resolution, while the recordings for the after study have a 480p resolution. The lower resolution video may have resulted in lower accuracy in the detection of vehicle and pedestrian movement in the after-study data.

RESULTS

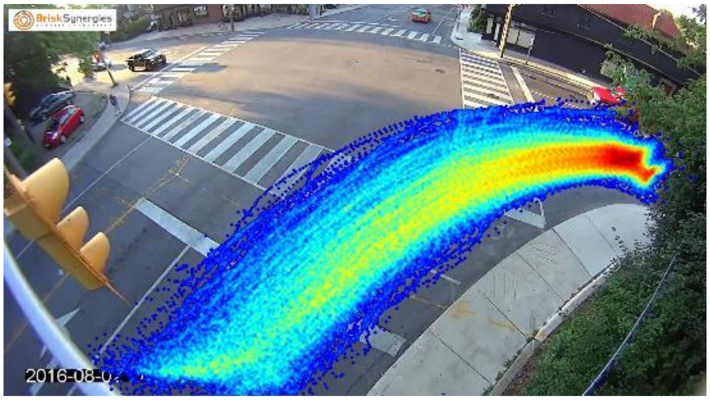
Safety Scenario

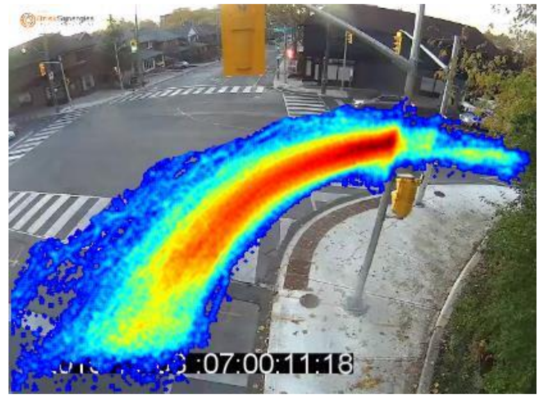
In this study, the interaction between the following two movements is analyzed using data mined from the video recordings:

- Southbound vehicles on Christie turning right onto Davenport
- North-south pedestrians on Christie crossing Davenport

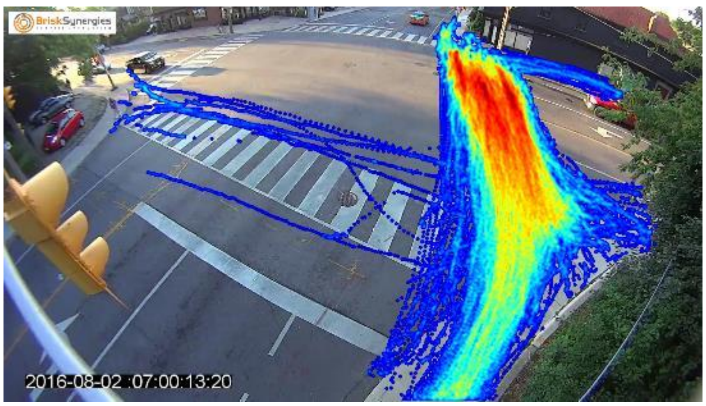
Trajectory Heatmaps

The trajectory heatmaps (Fig.3) show the most and least used map locations, indicating how accurately the software can detect the turning vehicles/crossing pedestrians to be studied without including other vehicle/pedestrian movements.





a) Vehicle, before b) Vehicle, after



c) Pedestrian, before d) Pedestrian, after

Figure 3. Trajectory heatmaps, before and after curb radius reduction

Speed Distributions

Vehicle speed distributions seem relatively similar before and after the modification of the curb radius (Fig 4.). In fact, the normalized before and after distributions show that after curb modification, there were fewer vehicles traveling at speeds less than 25 km/h, and more vehicles traveling at speeds greater than 25 km/h.

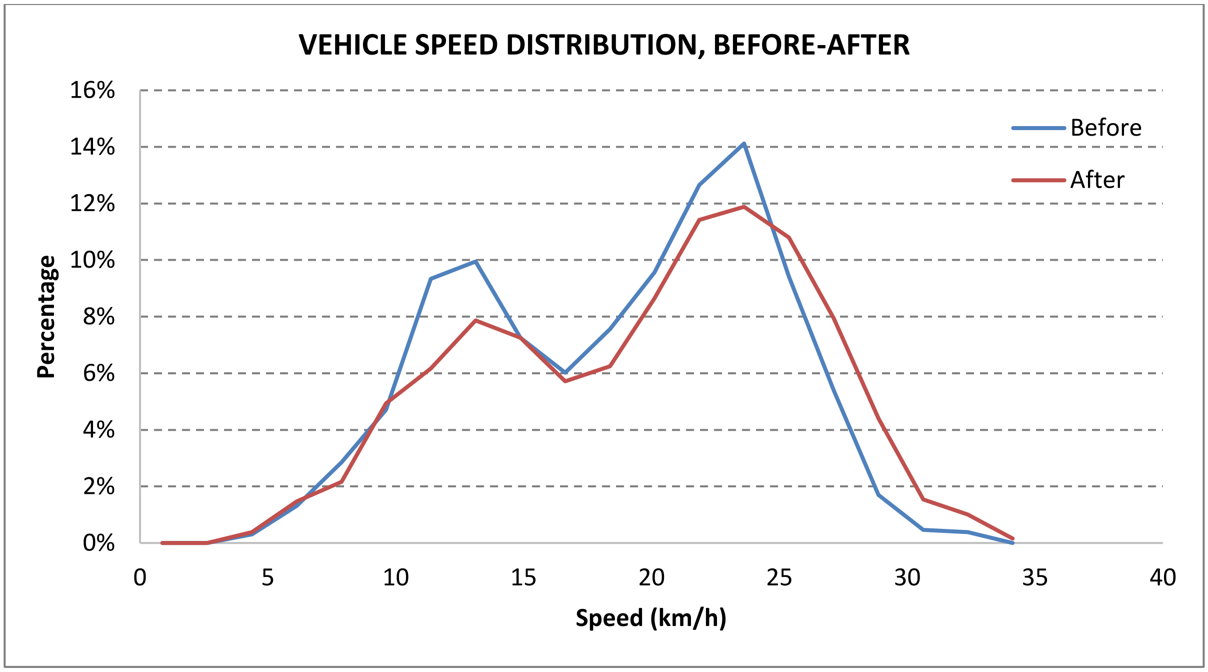


Figure 4. Vehicle speed distribution, before and after curb radius reduction
Before: 1335 vehicles, Average = 18.7 km/h, Std. Dev. = 5.8 km/h, Median = 19.7 km/h
After: 1298 vehicles, Average = 19.7 km/h, Std. Dev. = 6.3 km/h, Median = 20.9 km/h

Pedestrian speed distributions before and after curb modification were similar:

- Before: 600 pedestrians, Average = 6.9 km/h, Std. Dev. = 2.8 km/h, Median = 6.0 km/h
- After: 415 pedestrians, Average = 6.8 km/h, Std. Dev. = 3.4 km/h, Median = 5.7 km/h

Conflict Locations and Distribution

The frequency of conflicts at all risk levels is significantly reduced by the curb radius reduction (Fig. 5).

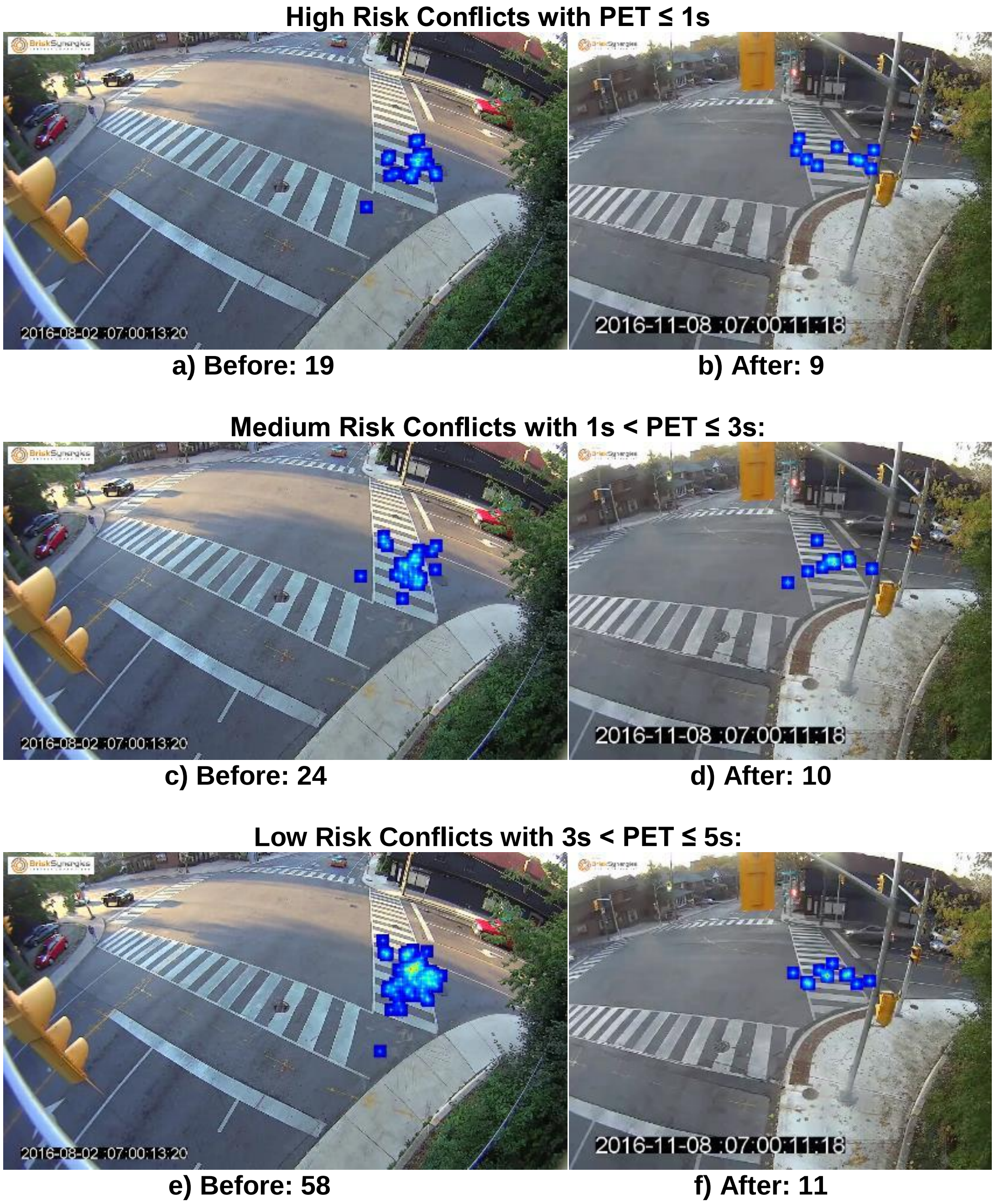


Figure 5. Heatmaps showing conflict locations, before and after curb radius reduction

Speed Distribution for Vehicles Involved in a Conflict

To further investigate the effect of curb radius reduction on the speed of turning vehicles, the speed distribution of vehicles that were involved in a conflict (with PET ≤ 3 seconds) is compared to that of vehicles that were not involved in a high/medium risk conflict (with PET > 3s). The average turning speed of vehicle-pedestrian interactions with PET ≤ 3 seconds was reduced (not significantly) after curb radius reduction. In other words, after the curb treatment, turning vehicles that interacted with pedestrians have lower speeds. However, for those vehicles not involved in interactions, speeds slightly increased after the treatment (not significantly) (Fig. 6, Table 1).

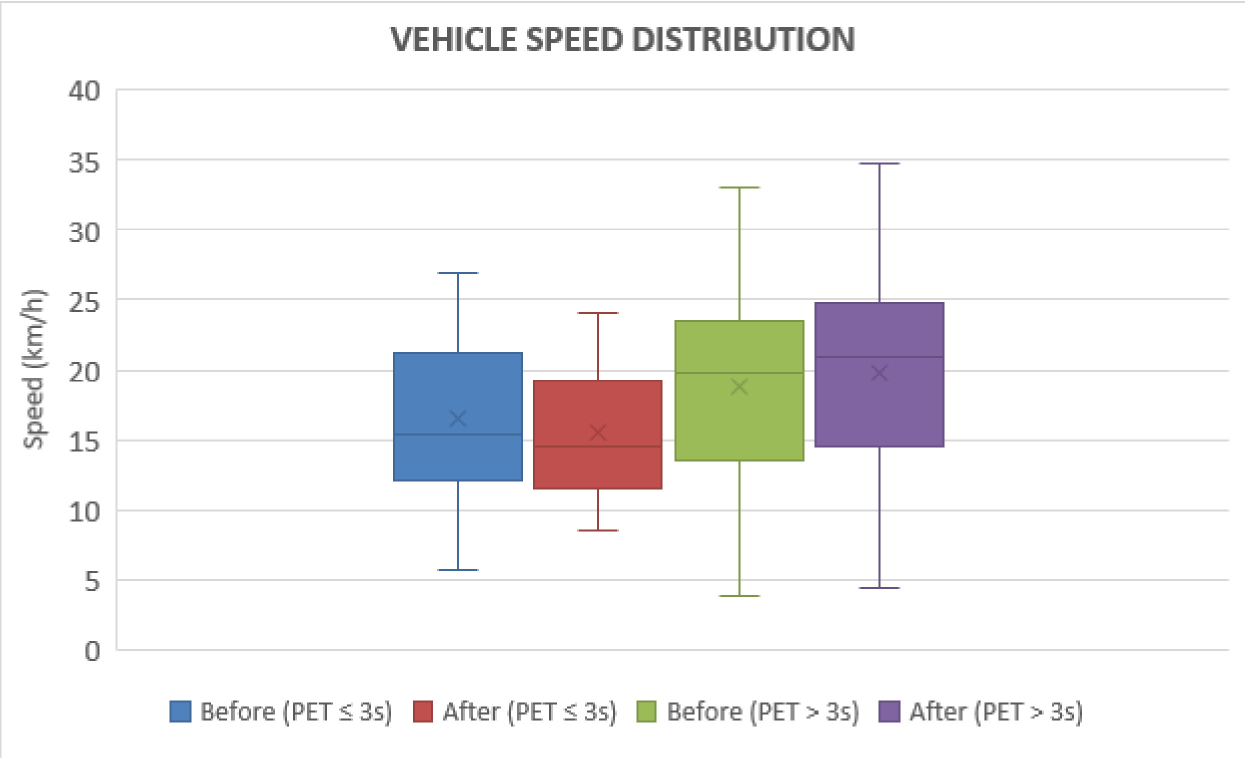


Figure 6. Turning vehicle speed distributions, before and after curb radius reduction for vehicles involved in a conflict (PET ≤ 3 seconds) and vehicles not involved in a conflict (PET > 3 seconds)

Table 1. Turning vehicle speed distributions for Before/After and with PET less/greater than 3 seconds

	PET ≤ 3s		PET > 3s	
	Before	After	Before	After
Average (km/h)	16.51	15.55	18.76	19.85
Median (km/h)	15.40	14.49	19.78	20.95
85th Percentile (km/h)	22.79	21.05	24.76	26.32

Risk Estimation

To normalize the number of conflicts based on the exposure measurement, and to estimate the risk, three different conflict rates are computed: high risk conflict with PET ≤ 1s, medium risk conflict with 1s < PET ≤ 3s, and low risk conflict with 3s < PET ≤ 5s. The before and after rates are compared to evaluate the effectiveness of the curb radius reduction at the intersection. The unit of these rates is “conflicts per potential million conflicts” and are defined as follows:

$$High\ Risk\ Conflict\ Rate = \frac{(NPET_H) * 10^6}{(Pedestrians\ per\ hour) * (Turning{-}Vehicles\ per\ hour)} \quad (1)$$

$$Medium\ Risk\ Conflict\ Rate = \frac{(NPET_M) * 10^6}{(Pedestrians\ per\ hour) * (Turning{-}Vehicles\ per\ hour)} \quad (2)$$

$$Low\ Risk\ Conflict\ Rate = \frac{(NPET_{\mathrm{L}}) * 10^6}{(Pedestrians\ per\ hour) * (Turning{-}Vehicles\ per\ hour)} \quad (3)$$

Where $NPET_H$, $NPET_M$, and $NPET_L$ are number of conflicts with 3s < PET ≤ 5s, 1s < PET ≤ 3s, and PET ≤ 1s, respectively.

SUMMARY

Conflict Rates

Conflict frequency and risk estimate rates decreased after the curb radius reduction (Table 2, Fig. 7, Fig. 8):

- Low Risk Conflict Rate was reduced by 72%
- Medium Risk Conflict Rate was reduced by 38%
- High Risk Conflict Rate was reduced by 30%

Table 2. Conflict frequency and risk estimates, before and after curb radius reduction

	Low Risk Conflicts		Medium Risk Conflicts		High Risk Conflicts	
	Count	Rate	Count	Rate	Count	Rate
Before	58	93,843	24	38,831	19	30,742
After	11	26,465	10	24,059	9	21,653

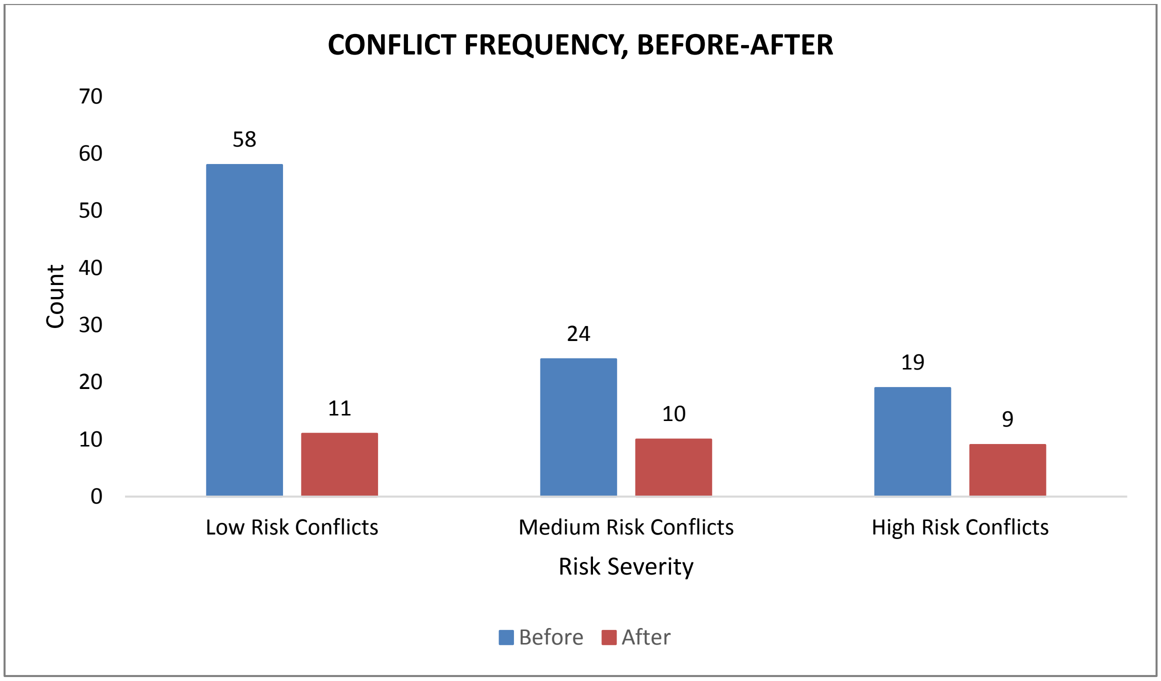


Figure 7. Conflict frequency, before and after curb radius reduction

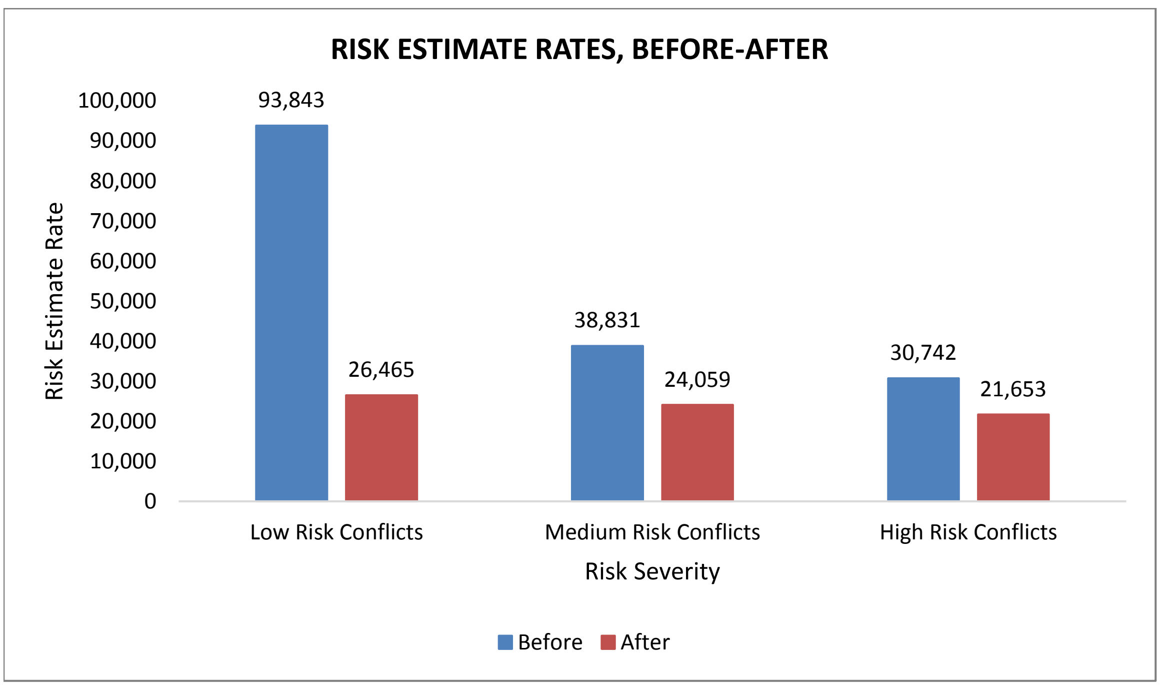


Figure 8. Risk estimate rates, before and after curb radius reduction

Vehicle Speed

After curb radius reduction, the speed of turning vehicles involved in a conflict (with PET less than or equal 3 seconds) dropped (Fig. 6 and Table 1):

- Average speed reduced by 5.8% from 16.51 to 15.55 km/h
- Median speed reduced by 5.9% from 15.40 to 14.49 km/h
- 85th Percentile speed reduced by 7.6% from 22.79 to 21.05 km/h

CONCLUSION

Using video analysis from before and after the curb radius treatment, surrogate safety analyses were successfully applied to evaluate the impact of the curb radius reduction at the signalized intersection of Davenport & Christie.

As expected, the analyses show that the curb radius reduction at the study intersection reduced conflict rates and the speed of turning vehicles involved in a conflict. The curb radius reduction was thus found to be an effective treatment for improving safety at this intersection.

One potential limitation of this study is that different video resolutions were used in the before and after studies. However, using conflict rates instead of conflict frequencies reduce the impact of lower detection rates caused by lower resolution. Another shortcoming of this study was lake of control intersection to control for other variables like weather difference between before and after study. A similar approach will be used to study the effect of the curb radius modification at the intersection of Yorkwoods & Driftwood. The geometric modification was complete in late 2016 and the after study is planned for Spring 2017. General safety benefits of tighter curb radii are widely accepted and incorporated into design guidelines of many North American jurisdictions. More intersections with this type of treatment could be studied to further quantify the magnitude of this safety countermeasure.

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