



Stantec

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January 17, 2018
File: 160401302

Attention: John Bernier

Planner – Development Review - South
110 Laurier Avenue West
Ottawa, Ontario
K1P 1J1

Dear John,

**Reference: 3500 Hawthorne Road Transportation Impact Study
Response to Transportation Comments / Public Concerns**

Further to our meeting of January 3, 2018, the following provides a response to the transportation comments from City staff received on December 4, 2017, including responses to concerns raised by the public related to this planning application.

The transportation-related comments that require resolution are summarized into the following topics:

- 1) Speeding concerns raised by the public;
- 2) Collisions related to the southbound right turn maneuver (i.e. from Hawthorne to Hunt Club)
- 3) Proposed Geometric modifications; and
- 4) Sight lines at the site accesses.

Speeding Concerns

At earlier public engagements related to this development application, members of the public expressed concerns related to the perception of high travel speeds in the area.

The posted speed limit along Hawthorne is 70 km/h and the posted speed limit along Hunt Club is 80 km/h.

The transportation environment near the site is conducive to higher travel speeds. Hawthorne Road, north of Hunt Club Road, has a five-lane cross-section with two through lanes in each direction plus a centre two-way left turn lane. The travel lanes are wide, the roadway cross-section is wide and straight and this type of roadway environment increases the level of comfort for motorists to travel at higher speeds. In addition, the risk of Police enforcement of traffic speeds is relatively low.



Reference: 3500 Hawthorne Road Transportation Impact Study, Response to Transportation Comments / Public Concerns

Similarly, Hunt Club Road is a four-lane divided arterial road with very few private accesses or intersections throughout the corridor. The low volume of accesses / intersections creates very little friction along the corridor, again, increasing the comfort for motorists to travel at higher speeds because the expectation is that they will not encounter many vehicles turning to / from sides streets or private accesses. Furthermore, now that Hunt Club road has an interchange with Highway 417, motorists who are exiting the Highway may still be transitioning from their Highway travel speed as they enter the more urbanized environment presented along Hunt Club Road.

What effect will the proposed development have on operating speeds?

The proposed development will contribute to a more urbanized or built-environment. As development fills in the vacant parcels around Hunt Club / Hawthorne, the intersection will act as a "gateway" or a transition area between the Highway / rural environment and the urban area of the City. It stands to reason, therefore, that the proposed development will contribute to lower operating speeds along Hunt Club Road and Hawthorne Road.

Furthermore, the proposed development will add two new accesses: a right-in/out access to Hawthorne Road and an egress to Hunt Club. These site accesses will create addition friction along the corridors which will also contribute to lower operating speeds.

Collisions

Stantec's November 15, 2017 letter-response to City comments summarized the results of a collision analysis at the Hawthorne Road / Hunt Club intersection. The collision analysis identified a high number of collisions associated with the southbound right turning maneuver (i.e. turning from the southbound right turn on Hawthorne Road to then proceed westbound along Hunt Club). During the three-year period between 2013 and 2015 it was found that 10 collisions occurred from within this maneuver. Upon closer examination, it was found that all 10 of these collisions occurred after the Hunt Club Road interchange with Highway 417 became open and fully operation in August of 2014.

What effect will the proposed development have on the collisions experienced by the southbound right turn maneuver?

As recommended in Stantec's March 2017 *3500 Hawthorne Road Transportation Impact Study*, the existing southbound right turn channel is proposed to be modified to reflect a "smart channel" design. Not only will the proposed modification increase the distance between the southbound right turn lane and the proposed egress to Hunt Club Road, a smart channel will decrease the angle of the channelized right turn to approximately 70 degrees. The intended goal of the smart channel is to a) reduce pedestrian crossing distance and therefore, pedestrian exposure to vehicles; and b) to improve vehicle to vehicle interactions since the new approach angle affords drivers with a better view of the traffic they are to merge with.



Reference: 3500 Hawthorne Road Transportation Impact Study, Response to Transportation Comments / Public Concerns

The Region of Waterloo, for example, found that smart channels have shown an 86% reduction in all rear-end collisions and a 73% reduction in rear-end collisions causing injury. The Region of Waterloo also highlights the advantage to pedestrians as the design helps to reduce vehicle speeds.

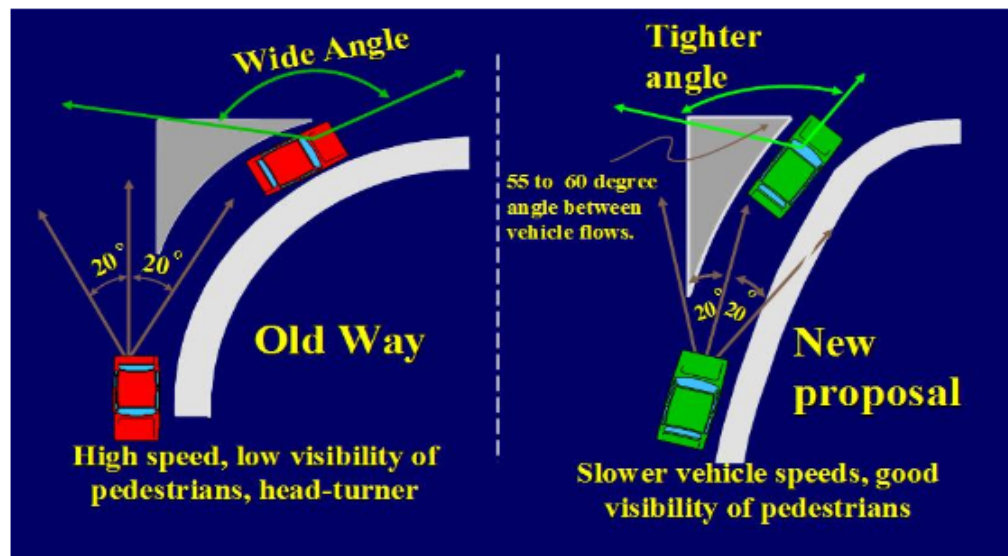


Image Source: <http://www.regionofwaterloo.ca/en/safehealthycommunity/trafficsafety.asp#rightturnsmartchannel>

A journal paper by Shattler and Hanson from Bradley University in Illinois that was published by the Transportation Research Board found through a before-and-after analysis a 44% reduction in total intersection collisions and 60% reduction in right-turn approach collisions after implementing the smart channel design. The journal paper is attached in **Attachment A**.

A journal paper by Sayed, Zaki, and Autey studied three smart channels in British Columbia and observed a 67% reduction in traffic conflicts after implementing the smart channel design. The journal paper is attached in **Attachment B**.

As shown in recent research, the proposed implementation of a smart channel design for the southbound right turn lane at the Hunt Club Road / Hawthorne Road intersection is expected to significantly reduce collisions for the southbound right turn movement and the intersection as a whole.

What effective will the proposed egress to Hunt Club have on collisions?

The proposed site egress to Hunt Club Road will introduce a conflict point on Hunt Club Road where one currently does not exist. As such, vehicles exiting the site have the potential to come into conflict with vehicles on Hunt Club Road, which increases the potential for collisions. However, this



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is generally the case with most developments that introduce new site access/egress so this situation is not unique to the subject development.

In summary, while the smart channel design has the potential to significantly reduce collisions experienced by the southbound right turn movement at the Hawthorne Road / Hunt Club Road intersection, the site egress to Hunt Club Road has the potential to increase conflicts / collisions on Hunt Club Road.

Proposed Geometric Modifications

The proposed geometric modifications, which will be submitted through a Roadway Modification Approval package, are summarized as follows:

- Reconstruction of the channelized southbound right turn lane (Hawthorne to Hunt Club) to reflect a smart channel design that accommodates a WB-20 design vehicle;
- Modifications to the existing median on Hawthorne Road to extend 15m north of the proposed site access; and
- Extension of the existing southbound right turn lane across the site frontage to accommodate the full length of a WB-15 design vehicle turning into the site access. Minor modifications may be required to the throat width and/or curb radii of the access to Hawthorne.

Sight Lines at the Site Accesses

Sight lines at the proposed site accesses were examined in the field to determine if adequate sight distance could be achieved.

At the proposed access to Hawthorne Road and facing north, it was found that two trees within the road right of way (i.e. between the private fence and the sidewalk) have the potential to obstruct sight lines (see image to right), particularly during summer months when the trees are in full bloom. It is recommended to cut down or trim back these trees such that they do not protrude beyond the hydro poles.

Sight lines from the proposed egress to Hunt Club Road were found to be adequate.





January 17, 2018
John Bernier
Page 5 of 5

Reference: 3500 Hawthorne Road Transportation Impact Study, Response to Transportation Comments / Public Concerns

We trust the above addresses the City's outstanding Transportation Comments related to the development application at 3500 Hawthorne Road, including concerns raised by the public. A Roadway Modification Approval submission is being prepared to reflect the geometric modification summarized in this letter and will be submitted shortly.

Should you have any further questions or concerns related to the above, or should you wish to discuss in more detail, please feel free to contact the undersigned at your earliest convenience.

Regards,

Stantec Consulting Ltd.

A handwritten signature in blue ink, appearing to read 'Robert Vastag'.

Robert Vastag, RPP
Senior Transportation Planner
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Attachments:

Attachment A: "Safety Impacts of a Modified Right Turn Lane Design at Intersections", Schattler and Hanson, Department of Civil Engineering and Construction, Bradley University, Illinois, November 2015.

Attachment B: "A Novel Approach for Diagnosing Road Safety Issues Using Automated Computer Vision Techniques", Sayed, Zaki and Autey, Department of Civil Engineering, University of British Columbia, Vancouver, BC, May 2013.



Reference: 3500 Hawthorne Road Transportation Impact Study, Response to Transportation Comments / Public Concerns

Attachment A: "Safety Impacts of a Modified Right Turn Lane Design at Intersections", Schattler and Hanson, Department of Civil Engineering and Construction, Bradley University, Illinois, November 2015.

1 **Safety Impacts of a Modified Right Turn Lane Design at Intersections**

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33 This paper is being submitted for presentation and publication at the 95th Annual Meeting of the
34 Transportation Research Board, January 2016, Washington, D.C.
35
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37 Word Count = 5,424 + 2000 (8 x 250) = 7,424
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40 Submission Date: November 15, 2015

ABSTRACT

From 2006 to 2014, ten right turn approaches in the Peoria, Illinois area were selected and reconstructed with a modified right turn lane design. The major purpose of the modified design was to improve the line of sight for passenger vehicles attempting to turn right, while also accommodating semi-tractor trailer trucks. While the actual changes varied among intersections, the final result at each was an improvement to the approach angle for right turning vehicles stopped to view cross traffic. The authors of this paper are involved in funded research to study the impacts of the modifications, utilizing a driver behavior analysis and a crash-based safety evaluation. The driver behavior field investigations, which included both a comparative test and control analysis at ten sites, and a before and after analysis at three sites, indicated that line of sight and approach angle was improved due to less drivers requiring exaggerated head turns to complete the right turn, less roll and go stops, and more vehicles stopping at the stop bar when a stop was required. Additionally, the crash-based safety analysis, using the Empirical Bayes method revealed statistically significant reductions in total intersection crashes and right turn related crashes at the subject approaches after the modifications were made. Based upon these results, it is recommended that improving the right turn approach angle by reducing the skew of the right turn approach be considered as a safety measure for sites experiencing right turn related crashes.

INTRODUCTION

According to NHTSA, intersection-related crashes account for approximately 47% of all crashes and 27% of fatal crashes in the United States (1). Within Illinois they accounted for approximately 39% and 26% of total and fatal crashes, respectively (2). Beyond this, FHWA estimates that intersection related crashes add up to \$40 billion annually in societal costs (3).

Transportation professionals commonly conduct studies to examine intersection designs and determine how they correlate to specific crash types. Of recent concern is the exclusive right turn lane design and right turn crash experience. Historically, exclusive right turn lanes have been associated with improved safety since they separate turning vehicles from through traffic. There are different types of geometric configurations for right turn lanes based on the design elements used and method of control of the right turn movement including: right turn lane with pavement marking, right turn lane with channelized island, and other variations. Some engineers think that right turn lanes with certain configurations may not provide the safety benefit they once believed, especially for right turn lanes with channelized islands. Some hypothesize that when channelized islands and turning roadways are used in the design, rear-end crashes may increase due to "collisions with vehicles stopping at the end of the turning roadway, or to drivers being more focused on looking upstream in preparation of the merging task rather than scanning to the right for potential pedestrians" (4).

When designing right turn lanes on state routes, since they are often designated as class I and II truck routes, regardless of truck volume and percentage, they must be designed to accommodate semi-tractor trailer trucks as the design vehicle (WB-67). In many states including Illinois, and as per the AASHTO Policy on Geometric Design of Highways and Streets (5), this results in a right turn lane design with large turning radius (200-50-600 foot three-centered curve) and a channelized corner island, especially if trucks encroaching into other lanes is discouraged in the design. When the intersection angle is 90 degrees, this radius may place passenger vehicles at an excessive approach angle to the intersection. If the intersection is

1 skewed, the approach angle for right turning passenger vehicles may pose further challenges due
2 to reduced sight distance.

4 **BACKGROUND**

5 A study performed in Texas examined the vehicle speeds associated with various right turn lane
6 designs as well as the crash experiences of the various designs. It was found that both the
7 approach speed and speed of vehicles in the middle of the turn increased with larger turn radii.
8 Additionally, the channelization of the turn lane resulted in lower approach speeds but slightly
9 increased speeds within the turn. The crash-based portion of this study, based on three years of
10 data at nine sites in Texas, found that most right turn rear-end crashes occurred at channelized
11 turn lanes, while shared through-right lanes experienced the lowest number of crashes (4). The
12 results of this study supported the observations of a similar study performed by Dixon et al. (6).
13 This study examined two years of crash data for seventy right turn movements. Final results
14 found that shared through-right lanes experienced the lowest number of right turn related crashes
15 per site, while exclusive right turn lanes with raised islands (channelized turn lanes) experienced
16 the most.

17 A study conducted by Harwood sought to investigate the safety effectiveness of installing
18 left and right turn lanes for at-grade intersections. The results of this study revealed that
19 signalized and unsignalized intersections in both rural and urban areas experienced reductions in
20 total crashes with the addition of a right turn lane (7). It should be noted however, that this study
21 did not examine the actual design of the right turn lane added.

22 Tarawneh published findings examining right turn on red (RTOR) maneuvers, and sought
23 to determine the effects of the right turn geometry as well as age and gender on these maneuvers.
24 This study examined driver behavior by whether a RTOR was attempted, use of side mirrors to
25 make ROTR, whether a RTOR was actually performed, complete stop or not before RTOR, right
26 turn free flow speed, and post turn accelerations. Additionally, the impact of turn radii were
27 measured by entrance, center, and exit distances from the curb; judged by the front right wheel at
28 established points along the curve. Results found that drivers 75 years and older are less likely to
29 attempt ROTR, use side mirrors when attempting ROTR, and also turn right at slower speeds.
30 Additionally it was found that at channelized right turn lanes, younger drivers are more likely to
31 use side mirrors for ROTR maneuvers, make a RTOR without stopping, and turn at higher
32 speeds. With regards to geometrics, it was found that larger radii resulted in turn paths being
33 more in line with the pavement edge, and higher turn speeds (8,9).

34 Focusing on intersection skew, a study by Garcia examined line of site conditions to
35 identify undesirable levels of intersection/vehicle skew. It was found that with intersection skews
36 between 40 and 55 degrees, the driver head turn required to view cross traffic is difficult for
37 drivers (specifically older drivers) and outside mirrors do not provide vision of the intersecting
38 streets (10). Additionally, the ITE Traffic Engineering Handbook proposes that while 90 degrees
39 intersections are always preferred, it is undesirable to ever skew intersections below 75 degrees
40 (11). ITE's recommended practice for context sensitive solutions suggests that the head-turn
41 angle for drivers turning right should be less than 140 degrees to improve pedestrian safety in
42 right turn maneuvers (12).

43 A study by Potts et al. created models examining various types of right turn related
44 crashes (13). Significant findings from the study found that channelized right turn lanes had a
45 lower crash frequency than right turn lanes without channelization, but greater than shared

through-right lanes. It was also found that conventional right turn lanes have 70-80% more pedestrian crashes.

Sayed et al. conducted a safety evaluation of Smart Channels (modified right-turn channels that reduce the right-turn angle to approximately 70 degrees) at three right turn approaches in British Columbia by observing traffic conflicts at the improved locations. The three test approaches were all cross streets to a major thoroughfare. The authors state that the goal of the Smart Channels is to “reduce the pedestrian crossing distance which can lead to shorter distance exposure, shorter signal cycles, and reduced potential for pedestrians to be in conflict with vehicles” (14) as well as to improve “vehicle to vehicle interactions since the new approach angle affords drivers a better view of the traffic stream they are to merge with” (14). The authors collected before and after traffic conflict data at the three sites and one control site, and concluded that an overall 67% reduction in traffic conflicts was observed, significant at 90% level of confidence (14).

Most of these research papers stated that more studies are needed to provide additional insights on the safety effects of different right turn treatments. Research papers that investigate the safety benefits of converting existing right turn lanes with traditional designs to alternative designs on state routes, based on analysis of traffic crashes, were not found in the literature. Thus, this research, containing an analysis of traffic crashes and driver behavior at the improved intersections in the Peoria area, contributes to the state-of-the-art and may also assist transportation agencies in determining the safety implications of right turn lane designs.

STUDY PURPOSE AND METHODOLOGY

The Illinois Department of Transportation (IDOT) commissioned a research study in the fall of 2011 to evaluate the safety impacts at ten intersection approaches in the Peoria, Illinois area that were reconfigured to improve the approach angle. The effectiveness evaluation involves both a field observational study of driver behavior and a crash-based evaluation at the study intersections.

Overall the changes made to the study approaches included sharpening the flat approach angle typical in the traditional designs, reducing the radius, adjusting the stop bar position, and modifying the corner island to improve safety by increasing the line of sight of approaching through traffic. The actual changes made to each intersection varied depending upon the initial design as well as site specific conditions. At some locations, the corner island was removed, and at other locations, pavement markings were provided to delineate the path for passenger vehicles. Figure 1 shows a generic sketch of the traditional and modified right turn lane designs.

The traditional design has a flatter approach angle combined with a larger radius, which may increase the speed of right turning vehicles. The flatter approach angle also requires a large degree of head rotation by the driver to screen for oncoming traffic from the left. The modified design has several expected advantages compared to the traditional. It may result in slower speeds that provide more safety for other vehicles and pedestrians, and it may require a significantly smaller degree of head rotation by drivers. This reduced head rotation would make it easier for drivers to monitor oncoming traffic and make safe merging decisions.

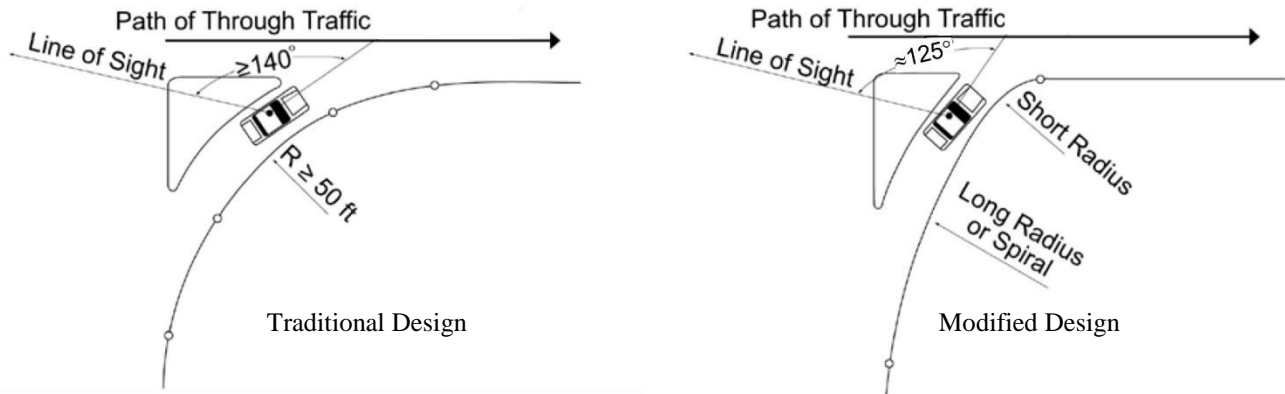


FIGURE 1 Generic right turn lane configuration for traditional and modified design.
Adapted from an illustration in ITE's *Transportation and Land Development* (15)

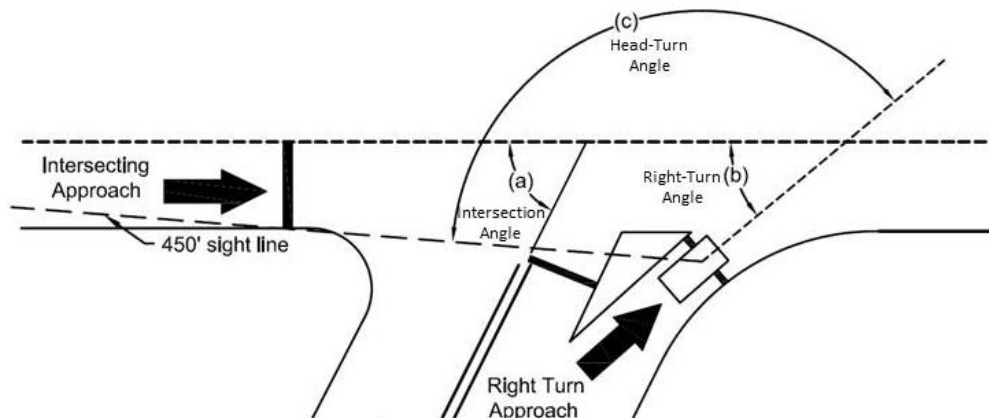
The purpose of this paper is to present the results of the field investigations of driver behavior and the crash-based effectiveness evaluation. The field investigation of driver behavior portion of the research sought to quantify differences in head turn extensions, stop/yield behavior of motorists, and stop location at test and control sites. The control sites had the traditional right turn lane design and the test sites were reconstructed to the modified design. Comparisons in driver behavior were then made between the ten paired test and control sites. Additionally, at three sites, field observations were conducted before and after the approaches were reconstructed. This allowed the authors to make comparisons between the results of the test and control observations with before and after driver behavior observations. The crash-based evaluation included an extensive analysis of three years of before data and three years of after data at seven test sites. Two experimental plans were used to assess the effectiveness of the modified right turn lane design including the Naïve Before and After and the Empirical Bayes method. Three of the ten sites were excluded from the crash-based evaluation presented here because of limited after data being available. Three of the sites were reconstructed in 2013 and 2014 and only 20 months of after data was available, which is not sufficient for inclusion in a safety effectiveness evaluation (16).

SITE DESCRIPTION

Test and control sites were used in the driver behavior field investigation. The control sites were selected based on their similarity to the respective test site's pre-construction (before) characteristics. Test and control sites were paired based on their similarities in intersection control, subject road laneage, intersection angle, right turn angle, head turn angle, right turn radius (measured as a single curve as opposed to a three centered curve), annual average daily traffic (AADT), presence of exclusive right turn lanes, downstream characteristics of the right turn movement, and other characteristics. The research team utilized aerial images to extract the intersection angle, right turn angle, head turn angle and radius. All traffic volume data was gathered from IDOT's traffic count website. Table 1 presents the characteristics at the ten paired test and control sites. The angles described in Table 1 are illustrated in Figure 2.

1 **TABLE 1 Characteristics of Test and Control Sites**

	Intersection	Subject Right Turn Approach	Traffic Control at Subject Right Turn	Subject Road Laneage	Inter-section Angle ^a (a)	Right Turn Angle ^a (b)	Head Turn Angle ^a (c)	Radius ^a	Inter-section AADT ^b
Test	Prospect & Knoxville	WB	Signalized	2 Lanes	54	22	141	155	29217
Control	Allentown & Court	WB	Signalized	2 Lanes	76	40	126	136	24525
Test	Northmoor & Knoxville	EB	Signalized	3 Lanes	86	42	133	100	28483
Control	N Frye & Knoxville	EB	Signalized	3 Lanes	75	32	143	199	25242
Test	Airport & IL 116	NB	Signalized	3 Lanes	64	30	142	299	15650
Control	War Memorial & Willow Knolls	WB	Signalized	3 Lanes	68	23	154	240	29825
Test	Wesley & IL 29	SB	Signalized	2 Lanes	57	30	142	302	29992
Control	Veterans Parkway & Morrissey	WB	Signalized	8 Lanes	63	33	137	207	37363
Test	Douglas & IL 116	NB	Stop	2 Lanes	58	34	148	206	15558
Control	Park Ave & Court	EB	Stop	2 Lanes	65	45	132	45	23550
Test	Adams & War Memorial	NB	Stop	1 Lane	84	25	153	74	19254
Control	I-74 & Washington	NB	Stop	2 Lanes	87	39	131	83	13200
Test	Adams & War Memorial	SB	Stop	1 Lane	81	33	143	62	19004
Control	I-74 & Washington	NB	Stop	2 Lanes	87	39	131	83	13200
Test	I 155 & Broadway	SB	Stop	1 Lane	67	37	137	140	5675
Control	I 155 & Broadway	WB	Stop	2 Lanes	69	38	139	143	3300
Test	McClugage & IL 8	SB	Signalized	4 Lanes	80	37	136	75	22250
Control	War Memorial & Adams	EB	Signalized	3 Lanes	89	39	139	124	23717
Test	Sterling & Farmington	SB	Signalized	4 Lanes	72	38	139	92	41300
Control	War Memorial & Adams	EB	Signalized	3 Lanes	89	39	139	124	23717

2 ^a Represents the before condition value at the test approaches. Angles are defined in Figure 2.3 ^b Average of 2008 to 2012 AADT data18 **FIGURE 2 Illustration of various geometric features and angles.**

FIELD INVESTIGATION OF DRIVER BEHAVIOR

Data Collection

In order to observe and quantify changes in driver behavior at the approaches with the modified right turn design, field data were collected at each of the ten test sites and ten paired control sites. The field data consists of four main variables: driver head turn behavior, lateral placement in the turn lane, stop type and stop location.

Field data were collected between May 2012 and July 2015. To have a comprehensive understanding of driver behavior, a total of eight hours of data were collected at each site, resulting in a total of 160 hours of observations (80 hours at the test sites plus 80 hours at the control sites.) An extended PM Peak Period (3:00 PM to 7:00 PM) on typical weekdays (Tuesday, Wednesday, or Thursday) was chosen for the observation period, and the data were collected on two days at each site. A total of nearly 19,000 vehicles were observed at the test and control sites combined.

In order to ensure a comprehensive set of data, a video recorder and two observers with voice recorders were used to collect driver behavior data. The observers took a verbal account of driver behavior with the voice recorders, with the video to be used as a reference. Every right-turning vehicle that approached the subject right turn during a red signal was observed. One observer recorded the driver head turn behavior prior to completing the turn, as well as the lateral placement of the vehicle in the turn lane. The other observer recorded the type of stop and the location of the stop relative to the stop bar. The variables collected are defined in Table 2.

TABLE 2 Description of driver behavior variables observed when a stop was required.

Type of Head Turn	Description
No Look	The driver does not observe upstream traffic within the data collector's vantage
Normal	The driver simply turns his head to observe upstream traffic
Exaggerated	The driver turns his shoulders or body, leans far forward, or other extreme movements to observe upstream traffic
Lateral Placement	Description
Inside/Curbside	The vehicle travels in the part of the lane closest to the curb
Middle	The vehicle travels in the middle of the lane
Outside	The vehicle travels in the part of the lane closest to the right turn island
Stop Type	Description
Complete or Near Complete	The vehicle either comes to a complete stop, or stops all forward momentum but the tires don't completely stop
Rolling	The vehicle slows down substantially but does not stop its forward momentum
Roll and Go	The vehicle fails to slow down or reduce speed
Stop Location	Description
On or Before the Stop Bar	The vehicle stops either with its front tires before the stop bar or with the stop bar between its front and back tires
Past the Stop Bar	The vehicle stops with its back tires beyond the stop bar

Before conducting the analysis, the authors of this paper developed four main hypotheses on how driver behavior would differ in response to the modified right turn design, as compared to the traditional design, when stopped in the right turn lane. Each of the hypotheses state that less occurrences of the critical/undesirable variables would be observed at the test sites as compared to the control sites. The four critical variables are: exaggerated head turns, inside/curbside lateral placement (hugging the curb), roll and go stop type, and stop location being past the stop bar. The four main hypotheses are listed below:

1. The proportion of exaggerated head turns at the test sites would be less than the proportion at the control sites. This was expected because of the improvement in the driver's line of sight.
2. The proportion of vehicles with inside/curbside lateral placement at the test sites would be less than the proportion at the control sites. This was expected because of the shortened radii and the modification of the channelized island.
3. The proportion of vehicles "rolling and going" at the test sites (when a stop was required) would be less than the proportion at the control sites. This was expected because the flatness of the approach angle was improved, minimizing the tendency for drivers to continue on an angled path.
4. The proportion of vehicles who stopped past the stop bar at the test sites would be less than the proportion at the control sites. This was expected because of the improved approach angle and improved sight lines, drivers would not have to travel past the stop bar to see oncoming traffic.

The field observations of driver behavior for the critical variables were analyzed for the ten test sites and ten control sites, and the results were then compared on an aggregated basis. In addition, before and after comparisons were made for three sites where it was possible to collect before and after data, at the intersections of: McClugage and IL-8, Farmington and Sterling, and Broadway and I-155 SB Ramp.

Analysis and Results

Statistical analyses were conducted to determine whether significant differences existed in the critical variables due to the modified right turn lane design. The z-test for proportions (Equation 1) was used to determine the significance of the observed differences at a 95% level of confidence (LOC), significance level (α) of 0.05, and a one-tailed test, since a direction in the critical variables was hypothesized.

$$z_{\text{statistic}} = \frac{P_c - P_t}{\sqrt{p(1-p) \left(\frac{1}{N_c} + \frac{1}{N_t} \right)}} \quad (1)$$

Where:

- P_c = Proportion of driver behavior variable observed at control site
 P_t = Proportion of driver behavior variable observed at test site
 N_c = Number of observations at control site
 N_t = Number of observations at test site
 p = Estimate of overall proportion = $(N_c P_c + N_t P_t) / (N_c + N_t)$

The z-statistic values were calculated and the corresponding p-values were obtained. The results of the statistical analysis for the test and control comparisons for the critical variables are shown in Table 3. For the before & after analysis, the aggregated before and after observations were used in place of the control and test variables in Equation 1, the comparisons are shown in Table 4.

TABLE 3 Comparison of Critical Driver Behavior Variables at Test and Control Sites

	No. Observations		Proportion		Z- statistic	<i>p-Value</i>	Significant at 95% LOC?
	Control Sites	Test Sites	Control Sites	Test Sites			
Head Turn Behavior							
Exaggerated Head Turns	2,342	3,688	0.400	0.311	11.82	< 0.00001	Yes
Total Observed	5,852	11,869					
Lateral Placement							
Inside/ Curbside	783	4,864	0.134	0.410	-37.08	< 0.00001	Yes
Total Observed	5,852	11,869					
Stop Type							
Roll & Go	299	413	0.050	0.033	5.52	< 0.00001	Yes
Total Observed	5,948	12,358					
Stop Placement							
Past Stop Bar	1,937	1,310	0.547	0.196	36.2	< 0.00001	Yes
Total Observed	3,544	6,676					

TABLE 4 Before and After Comparison of Critical Driver Behavior Variables at Test Sites

Description	No. Observations		Proportion		Z- statistic	p-Value	Significant at 95% LOC?
	Before	After	Before	After			
Head Turn Behavior							
Exaggerated Head Turns	741	642	0.395	0.240	11.18	< 0.00001	Yes
Total Observed	1,876	2,674					
Lateral Placement							
Inside/ Curbside	505	758	0.247	0.283	-2.82	0.00241	Yes
Total Observed	2,046	2,674					
Stop Type							
Roll & Go	75	96	0.051	0.032	3.13	0.00088	Yes
Total Observed	1,477	3,020					
Stop Location							
Past Stop Bar	333	660	0.440	0.510	-3.07	0.00108	Yes
Total Observed	757	1,294					

The comparison between test and control right turn approach locations (Table 3) revealed that significantly less drivers utilized exaggerated head turns at the test sites (31.1%) than at the control sites (40.0%). This supports the assumption that the modified right turn design provides a

1 better line of site for drivers turning right, reducing the need to utilize an excessive head turns in
2 order to check for upstream traffic. The comparison also showed that more drivers traveled
3 through the inside part of the lane at the test sites (41.0%) than at the control sites (13.4%). This
4 result does not support the authors' hypothesis that the modified right turn design would
5 encourage drivers to position their vehicles in the middle of the lane. It was found that
6 significantly less drivers utilized roll and go stops at the test sites (3.3%) than the control sites
7 (5.0%). At the test locations, significantly less vehicles stopped past the stop bar (19.6%) as
8 compared to the control sites (54.7%), which indicates that the modified right turn design allows
9 vehicles to stop at the proper location, with adequate sight distance. Since drivers at the
10 modified right turn design use fewer exaggerated head turns, roll and go stops, and stops past the
11 stop bar, they will travel at slower speeds, have improved sight lines, and approach the right turn
12 with less skew.

13 As shown in Table 4, the before and after results were similar to the results of the test and
14 control site comparisons. Although the before and after comparisons were drawn from a smaller
15 sample of test sites, they do provide further support for the above-noted results.

17 **TRAFFIC CRASH-BASED SAFETY EVALUATION**

19 **Data Collection**

20 Three years of before crash data were obtained and analyzed for each of the seven test
21 approaches. Three years of after data is typically desired for crash-based evaluations, and
22 currently seven of the sites have three years of after data available. Three of the test sites were
23 excluded from this analysis, as only 20 months of after crash data is currently available. The test
24 sites included in the crash-based evaluation are:

- 25 ■ Prospect and Knoxville
- 26 ■ Northmoor and Knoxville
- 27 ■ Airport and IL 116
- 28 ■ Wesley and IL 29
- 29 ■ Douglas and IL 116
- 30 ■ Adams and Northbound War Memorial Ramp
- 31 ■ Adams and Southbound War Memorial Ramp

33 Crash report forms were obtained from IDOT and the crash narratives were analyzed to
34 help minimize possible coding errors. Crash data were collected within an assumed intersection
35 influence radius of 250 feet. Details of each crash were then extracted such as location
36 information, vehicle direction, injury severity, crash type, driver age, driver gender, roadway
37 conditions, and the primary contributory cause of the crash. Additionally, crashes that involved a
38 vehicle making a right turn maneuver from the subject approach were specifically noted. This set
39 of right turn-related crashes was of primary interest in this research because the treatment has the
40 largest expected impact on this targeted crash type.

42 **Analysis and Results**

43 Two methods were used to evaluate the crash experience at seven test right turn approaches: the
44 Naïve Before and After, and the Empirical Bayes method. These two methods seek to determine
45 the effectiveness, or percent reduction in crashes, that can be attributed to the countermeasure or
46 improvement. In this research, the improvement is the modified right turn lane design described

earlier. In both methods, the actual after crash frequency is compared to an expected value. The expected value represents the crashes that would have occurred in the after period had the safety improvements not been made at the test site. This expected value will never be known with 100% certainty because the conditions at the test site changed due to the improvements. The difference in the two evaluation methods lies in the determination of the expected value of the crashes without treatment.

Naïve Before and After (B&A)

In this method, the expected crash frequency in the after period, had the improvements not been made, is assumed to be the before crash frequency. Since the only major change made to the intersection was the modification of the right turn lane, it can be assumed that any significant change observed in crash frequencies would be a result of the modified design. Although this method fails to account for fluctuations common in crash frequencies over time, it still provides useful insight into the impact of the treatment.

Empirical Bayes (EB)

The random nature of crashes makes it impossible to truly predict the expected number of crashes in an after period, had the improvements not been made. The EB method is commonly accepted as a more precise estimation of the expected crashes than any other method due to its ability to account for regression-to-the-mean bias. The EB method takes into account both the crash experience of the test sites, and a crash prediction model, called a safety performance function (SPF) derived from the crash experience of numerous comparison sites. Once developed, this model is then weighted against the observed crash experience of the test site to more accurately predict the expected crashes. In this research, the procedure for the EB method as documented in the Highway Safety Manual (16) was used to conduct the analysis.

As a part of this research, four SPF models were developed to predict total intersection crashes, total intersection injury crashes, total crashes at the subject approach, and right-turn related crashes at the subject approach. The geometric characteristics, crash history and traffic volumes of a group of 116 comparison sites were compiled and analyzed using the IBM SPSS statistical analysis software. Assuming an underlying Poisson/ negative binomial distribution, which is a common assumption in modeling traffic crashes (16); SPF models were then developed to predict crashes using variables that were found to have a statistically significant influence on crashes observed at the comparison sites. Equations 2, 3, 4, and 5 show the form of the SPFs developed in this research, and Table 5 shows the coefficients and over-dispersion factors.

$$\mu_{Total} = e^{\alpha} \times e^{\beta_1 * RTappADT} \times e^{\beta_2 * INTRsappADT} \quad (2)$$

$$\mu_{Injury} = e^{\alpha} \times e^{\beta_1 * RTappADT} \times e^{\beta_2 * INTRsappADT} \quad (3)$$

$$\mu_{SubjectApp} = e^{\alpha} \times e^{\beta_1 * RTappADT} \times e^{\beta_2 * RTappSpeedLimit} \quad (4)$$

$$\mu_{RT} = e^{\beta_1 * HeadTurnAngle} \times e^{\beta_2 * RT Radius} \quad (5)$$

Where:

μ_{Total} = Average Annual Expected Total Intersection Crashes

μ_{Injury} = Average Annual Expected Total Intersection Injury (K,A,B,C) Crashes

$\mu_{\text{SubjectApp}}$ = Average Annual Expected Crashes at the Subject Approach

μ_{RT} = Average Annual Expected Right-turn Related Crashes at the Subject Approach

RTappAADT = AADT of the right turn approach

INTRSappAADT = AADT of the intersecting through approach

RTappSpeedLimit = Posted speed limit (mph) at the right turn approach

HeadTurnAngle = Measured head-turn angle for right turning vehicle at approach

RT Radius = Measured radius of right-turn lane (ft)

α = Regression Model Intercept

β_1, β_2 = Regression Coefficients

TABLE 5 Variable Coefficients for Safety Performance Functions

	Regression Coefficients			Over-Dispersion Parameter (ν)
	Intercept (α)	Coefficient (β_1)	Coefficient (β_2)	
Total Intersection Crashes	2.210	5.249×10^{-5}	4.020×10^{-5}	0.109
Intersection Injury (K,A,B,C) Crashes	0.848	4.570×10^{-5}	3.315×10^{-5}	0.029
Subject Approach Crashes	1.253	2.807×10^{-5}	0.018	0.079
RT Related Crashes at Subject Approach	NA	0.012	0.003	0.145

NA = Not Available

The results of the EB method are influenced by the selection of SPFs used in any analysis. In order to validate the SPFs developed by the research team, the predicted/expected crash frequencies were compared to those using other published SPFs developed for the State of Illinois (17). For the Illinois-specific SPFs (17), injury crash prediction models are only available, thus comparisons in the predicted intersection injury crash frequency between the SPF developed in this research with the published SPF (17) was the only comparison that could be made. The predicted annual average crash frequencies for the SPFs developed through this research and the Illinois-specific SPFs were 22.93 and 22.16, respectively. The similarity in predicted values validated the use of the SPFs developed as a part of this research for all four crash types.

The effectiveness evaluation results for both methods are shown in Table 6. The observed crash reductions were tested for statistical significance using the Poisson test at 95% LOC.

TABLE 6 Results of Crash-Based Effectiveness Evaluation

	Annual Average Crash Frequency				
	Observed/ After	Naïve B&A Expected	Naïve B&A Reduction	Empirical Bayes Expected	Empirical Bayes Reduction
Total Intersection Crashes	53.67	91.33	41.2% *	95.47	44.2% *
Intersection Injury (K,A,B,C) Crashes	13.00	21.33	39.1% *	22.93	43.6% *
Subject Approach Crashes	21.67	57.33	62.2% *	52.43	58.9% *
RT Related Crashes at Subject Approach	15.00	53.67	72.0% *	37.50	60.3% *

* Denoted statistical significance at 95% LOC

As shown in Table 6, each method indicates that a significant reduction in right turn related crashes at the test approaches was observed in the after period. This provides evidence that the modified right turn design implemented in the Peoria, Illinois area provides a significant improvement to safety. The percent reductions for total intersection crashes ranged from 41.2 to 44.2% between the two methods. Total intersection injury crashes experienced percent reductions ranging from 39.1 to 43.6%. The percent reductions in subject approach crashes were observed as 58.9 to 62.2%. For right turn related crashes at the subject approach, the highest crash reductions were observed, ranging from 60.3 to 72.0%.

It appears that a majority of the reduction in total intersection crashes is accounted for in the reduction in right turn related crashes. This provides evidence that the modifications had a positive impact on reducing crashes at the study approaches, specifically those associated with the right turn lane.

SUMMARY AND CONCLUSIONS

From 2006 to 2014, IDOT implemented modifications to ten right turn approaches. The changes were intended to improve the line of sight of right turning passenger vehicles by reducing the skew of the approach angle, while at the same time continuing to accommodate large semi-tractor trailer trucks to make right turns without encroachment. This research provided the opportunity to study the impact of these changes, and provide information that may be used in future decision making.

The authors of this paper conducted an analysis of field observations of driver behavior at right turn lanes at ten test sites and ten control sites. The test and control comparisons revealed that a lower percentage of drivers made exaggerated head turns at the test sites (modified right turn lane design) than at the control sites (traditional design), supporting the hypothesis that the modified right turn design provides a better line of site for drivers turning right, reducing the need to utilize an excessive head turn in order to check for upstream traffic. The comparison also showed that more drivers traveled through the inside part of the lane at the test sites than at the control sites, which does not support the authors' hypothesis. It was found that significantly fewer drivers utilized roll and go stops at the test sites than the control sites, which minimizes the opportunity for traffic conflicts. At the test locations, significantly fewer vehicles stopped past the stop bar as compared to the control sites, which indicates that the modified right turn design

allows vehicles to stop at the proper location, with adequate sight distance. Since drivers at the modified right turn design use fewer exaggerated head turns, roll and go stops, and stops past the stop bar, they will travel at slower speeds, have an improved line of sight and approach the right turn with less skew. Before and after comparisons were only available at three test sites, due to the dates of construction. However, the results were similar to the test and control comparisons for three of the four critical variables and provide support for comparative test and control analysis.

The traffic crash-based evaluation of seven test approaches with three years of before and after data provides insight into the safety impact of the modified right turn lane design. The results of the Empirical Bayes method indicated statistically significant reductions in total intersection crashes (44.2%), intersection injury crashes (43.6%), subject approach crashes (58.9%), and right turn related crashes at the subject approaches (60.3%) at 95% LOC. Overall the safety evaluation provides evidence that modifying right turn lanes to improve the approach angle of right turn vehicles improves safety by reducing the frequency of right turn related crashes at the approaches, as studied in the Peoria, Illinois area.

Based upon the overall finding of the study, both the driver behavior and safety evaluations, the modification of right turn lanes to improve the approach angle of right turning vehicles has significant benefits. It is recommended that similar modifications to improve the right turn approach angle/position be considered as potential improvements for intersection approaches that experience a pattern of right turn-related crashes.

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Attachment B: "A Novel Approach for Diagnosing Road Safety Issues Using Automated Computer Vision Techniques", Sayed, Zaki and Autey, Department of Civil Engineering, University of British Columbia, Vancouver, BC, May 2013.



16th Road Safety on Four Continents Conference
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A NOVEL APPROACH FOR DIAGNOSING ROAD SAFETY ISSUES USING AUTOMATED COMPUTER VISION TECHNIQUES

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ABSTRACT

The use of traffic conflicts for safety diagnosis has been gaining acceptance as a surrogate for collision data analysis. The traffic conflicts approach provided better understanding of collision contributing factors and the failure mechanism that leads to road collisions. This paper demonstrates an automated proactive safety diagnosis approach for vehicles, pedestrian and cyclists using video-based computer vision techniques. Traffic conflicts are automatically detected and several conflict indicators such as Time to collision (TTC) are calculated based on the analysis of the road-user positions in space and time. Additionally, spatial violations are detected based on the non-conformance of road users to travel regulations. Several case studies are described. The first case study deals of the safety analysis of a newly installed bike lane at the southern approach of a heavy volume Bridge in Vancouver, British Columbia. The results showed a high exposure of cyclists to traffic conflicts. Practical solutions to address the safety issues at the location were presented. The second case study deals with a major signalized intersection where concerns were raised regarding the high conflict rate between vehicles and pedestrians as well as an elevated number of traffic violations (i.e., jaywalking) at the intersection. Conflicts and violations were identified and pedestrian safety countermeasures were presented. The third case study deals with a before-after (BA) safety evaluation of a newly proposed design for channelized right-turn lanes at intersections. The new design, termed “Smart Channels”, decreases the angle of the channelized right turn to approximately 70 degrees. The results of the evaluation show that the implementation of the right-turn treatment has resulted in a considerable reduction in the severity and frequency of merging, rear-end, and total conflicts. Overall, the three case studies demonstrate the considerable potential of using video-based computer vision techniques for automated road safety analysis based on traffic conflicts.

1 INTRODUCTION

The focus of this paper is driven by the potential of computer vision techniques for solving well-recognized problems in road safety and road user behavior analyses. The purpose of safety diagnosis studies is to identify factors that may be causing safety deficiencies at a particular location or a road segment. The use of traffic conflicts for safety diagnosis has been gaining acceptance as a surrogate for collision data analysis [1] [2] [3] as they provide insight into the failure mechanism that leads to road collisions. Traffic conflicts address several shortcomings associated with collision data such as the scarcity of collisions, the need for long observation times and the questionable quality of collision data. Yet, current on-site methods for collecting surrogate measures data are labour-intensive, suffer from reliability issues, time consuming and costly. Video sensors are now advocated as alternative data collection procedure, solving many issues in the manual data collection and providing a more reliable and efficient way to capture, store and analyze traffic information. The accurate estimation of exposure as well as other quantities fundamental to road safety analysis, e.g. severity of a traffic interaction, can greatly benefit by analyzing road users' positions in space and time, i.e. trajectories [4]. Video data is supported with practical computer vision applications (CV) to aid in the analysis of traffic scenes.

This paper demonstrates an automated proactive safety diagnosis approach for vehicles, pedestrian and cyclists using video-based computer vision techniques. Traffic conflicts are automatically detected and several conflict indicators such as Time to collision (TTC) are calculated based on the analysis of the road-user positions in space and time. Additionally, spatial and temporal violations are detected based on the non-conformance of road users to travel regulations. Three case studies are described. The first case study deals of the safety analysis of a newly installed bike lane at the southern approach of a heavy volume Bridge in Vancouver, British Columbia and practical solutions to address the safety issues at the location were presented. The second case study deals with a major signalized intersection in Vancouver where concerns were raised regarding the high conflict rate between vehicles and pedestrians as well as an elevated number of traffic violations (i.e., jaywalking) at the intersection. Conflicts and violations were identified and pedestrian safety countermeasures were presented. The third case study deals with a before-after (BA) safety evaluation of a newly proposed design for channelized right-turn lanes at intersections. The new design, termed “Smart Channels”, decreases the angle of the channelized right turn to approximately 70 degrees.

2 THE VIDEO ANALYSIS APPROACH

The safety analysis is performed using a video analysis procedure using computer vision, developed at the University of British Columbia. The video analysis system automatically detects, classifies, and tracks road users and interprets their movement. For road safety applications, the proposed approach relies on the building of two databases: a trajectory database, where the results of the video processing module are stored, and an interaction database, where all interactions between road users within a given distance are considered, and for which various conflict indicators can be automatically computed. Identifying road-users

16th Road Safety on Four Continents Conference Beijing, China 15-17 May 2013

behavior, traffic violations, traffic conflicts and measuring other traffic parameters can be achieved through mining these databases [4] .

Road-Users Detection: The automated video analysis relies on computer algorithms to differentiate between features of road users and features that are part of the environment [5]. Features are identified and tracked using an implementation of the Kanade-Lucas-Tomasi Feature Tracker algorithm [5]. Feature-based tracking identify distinguishable features (e.g. window corners, bumper edges) on the moving object. (See **Figure 1.a**). Since a moving object can have multiple features, the next step is to group the features, using spatial and temporal cues. (See **Figure 1.b**). The subsequent step in the road-users detection is the road-users classification. The objects trajectories hold features that reveal the structure of the traffic movements and provide important clues to the characteristics of the road-users (e.g. pedestrian ambulation, cyclist pedaling, maximum speed). Such information provides a basis for a classification decision procedure (See **Figure 1.c**). The road-users tracking and classification accuracy were presented in [6] and [7] where tracking error was reported to be satisfactory low.

Camera Calibration: The positional analysis of road users requires accurate estimation of the camera parameters. Camera calibration is the process of determining the homography matrix of a camera angle, and is necessary for tracking vehicles in the camera image and relating these tracks to positions in the real-world. Each calibration process begins with the user annotating features in the camera image and in an aerial, orthographic image of the intersection. Details of the adopted mixed-feature camera calibration approach are presented in [8].

Safety Analysis: The adapted safety analysis provides an operational interpretation to automatically capture the traffic conflicts between road-users. The implementation relies on matching the trajectories to prototypical trajectories from the full set of previously learned motion patterns [4]. (See **Figure 1.d**). The prototypes provide a set of predicted future positions with associated probabilities of occurrence. Conflicts between road-users can then be determined by evaluating if any of these future positions coincide spatially and temporally with other road-users (See **Figure 1.e**). Details of the procedure are explained in [4].

In this paper, the measure of proximity is Time to Collision (TTC). TTC is continually calculated between conflicting road-users. The minimum TTC, is then extracted from this set to indicate the maximum severity of this interaction. In this paper, only traffic events with associated minimum TTC of less than 3 seconds are considered for the safety evaluation. This value was selected based on the work in [3]. Other conflict indicators are also used to capture different proximity aspects. Post-Encroachment Time (PET) [9] is defined as the time difference between the moment an offending road user leaves an area of potential collision and the moment of arrival of a conflicted road user possessing the right of way. PET is considered as a suitable safety measure between turning vehicles and pedestrians [7].

16th Road Safety on Four Continents Conference
Beijing, China 15-17 May 2013



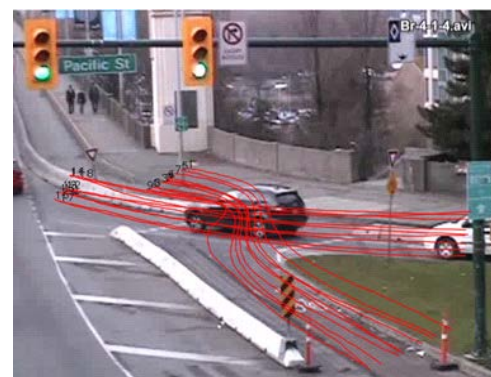
(a) Features Tracking



(b) Features Grouping



(c) Road-users Classification



(d) Trajectories Prototypes



(e) Event Detection

Figure 1: Demonstration of the Video Analysis Process

3 CASE STUDY 1: DIAGNOSING SAFETY ISSUES OF VEHICLES-BICYCLES INTERACTIONS USING AUTOMATED COMPUTER VISION ANALYSIS

The intersection analyzed in this study was selected because of perceived high rate of conflicts between vehicles and cyclists. **Figure 2** illustrates the conflicts regions for typical trajectories of the road-users. Right-turning vehicles in the ramp should yield for bicycles travelling southbound to the Burrard Street Bridge. However, the current configuration limits the available sight distance leading to severe conflicts. For the northbound approach of the intersection, a large portion of northbound cyclists will go off ramp onto another bike lane. Yet, some cyclists will have to cut through the vehicles right-turn lane in order to take the through lane towards Burrard Street.



Figure 2. Possible Conflicts Regions for Vehicles-Bicycles Interactions

4 SUMMARY OF FINDINGS

Traffic conflicts between vehicles and bicycles at both approaches of the intersection are automatically identified. Conflict analysis includes identifying conflict frequency, severity and location (conflict points). Distribution of the vehicle-bicycle conflicts (with a minimum TTC smaller than 3 seconds) by heat mapping is shown in **Figure 3**. Those conflicts considered of high severity were carefully analyzed leading to recommended safety countermeasures as will describe later.

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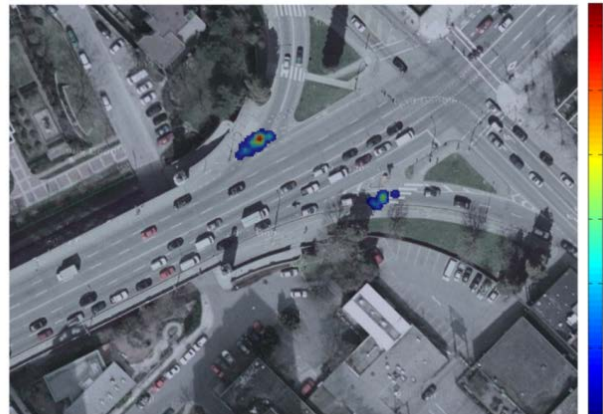


Figure 3: Conflicts Frequency Heatmaps (Conflicts/m²) for the Burrard & Pacific Intersection

Tables 1 shows a breakdown of the number of cyclist-vehicle conflicts by type and severity. For southbound traffic, the majority of the conflicts are between vehicles non-conforming to the yielding signage and the cyclists arriving from the Burrard Street bike lane and crossing towards the Burrard Bridge bike lane. This is attributed likely to the limited sight angle for the drivers who in most cases are not aware to the arrival of cyclists. Out of the 229 cyclists, 72 were in conflicts with vehicles as shown in Table 1, that is 31.44 percent of the cyclists. On the northbound approach, according to Table 1, 35 cyclists were in conflicts that 23 percent of cyclists traveling northbound. It is worth mentioning that only out of 149 cyclists; only 39 chose to travel on the bike lane crossing the vehicles heading to Burrard Street, while the remaining majority (110) chose an alternative safer path by going straight on the sidewalk.

The analysis of important events such as conflicts led to the proposal of some recommendations that can act as safety countermeasures. One recommendation is better signage and road markings. Cyclists crossing area should be clearly strip marked to indicate that vehicles should not stop in this area.

Table 1: Cyclist-Vehicle Conflicts for Burrard & Pacific Intersection

Conflicts	Southbound Bikes and Right-turn Vehicles (Camera angle 2)	Northbound Cyclists and Right-turn (Camera angle 3)
TTC range	# Events	# Events
0-1 seconds	34	19
1-2 seconds	23	16
2-3 seconds	15	0
TOTAL	72	35

Case Study 2: Application of Computer Vision to the Diagnosis of Pedestrian Safety Issues

The intersection analyzed in this study was selected because of a perceived high rate of conflicts between vehicles and pedestrians [10]. The site in the study is a busy eastside downtown intersection located at East Hastings and Main Streets as shown in **Figure 4**. There are several factors that affect safety at this location, including a high pedestrian volume with considerable crossing violations and jay walking. Four camera angles were selected for this location. Camera position 1 focused on area to the immediate east of the intersection, with the camera pointed southwards. The main movements observed in the scene are the eastbound through and northbound right turning vehicles (**Figure 4**). Two conflict types were considered in this view: northbound right turn vehicles with east-west crossing pedestrians and eastbound through vehicles with north-south crossing pedestrians. Camera position 2 pointed southwards to cover the south west segment of the intersection, capturing pedestrian crossings with southbound traffic at the southward crossing along Hastings Street. This camera position also captured conflicts between north-south pedestrians on the western crossing along Main St. with eastbound traffic. Camera position 3 complements the previous position by capturing the remaining part of the pedestrian western crossing along Main St. It also covers the western segment of the northern pedestrians crossing along Hastings St. Camera position 4 captures the mid-block pedestrian's violations (jaywalking).

5 SUMMARY OF FINDINGS

Traffic conflicts between vehicles and pedestrians at the intersection were automatically identified. The heat map in **Figure 5** shows the intensity of the vehicle-pedestrian conflicts at the intersection (conflicts/m²). Safety diagnosis is supported with an automated pedestrian violations (jaywalking) detection mechanism.

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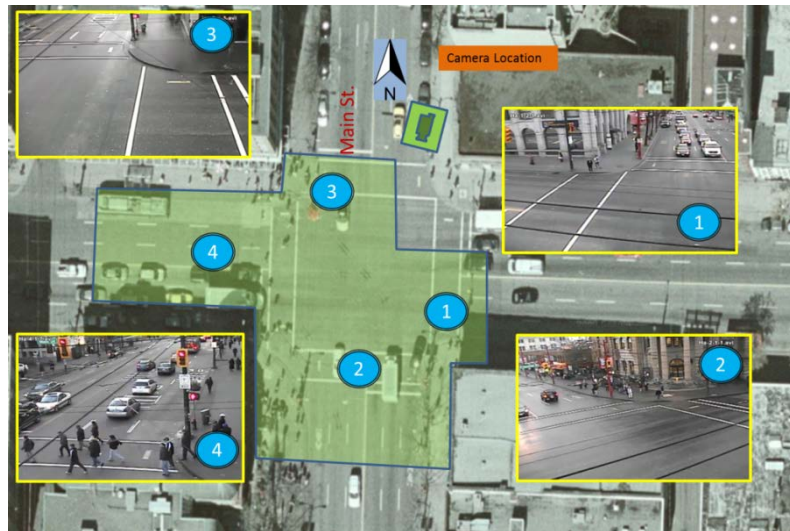


Figure 4: East Hastings St. and Main St. Intersection

It is observed that the majority of conflicts occur between right-turning or left turning vehicles and crossing pedestrians. Each of these turning movements can legally be undertaken during the pedestrian's walk phase, provided pedestrians are given the right of way. All of the pedestrian conflicts occur due to either vehicles ignoring the pedestrian's right of way, or pedestrians entering the crosswalk after the walk phase. Pedestrians crossing in the east approach are involved in frequent conflicts. Eastbound right turning vehicles and north bound pedestrians also frequently interact at the curb, when pedestrians first step into the crosswalk. Note that the left turn movement from the Northern approach is prohibited. From Camera location 2, it is observed that southbound right turning vehicles coming from the western approach on Hastings Street have a high occurrence of conflicts. More frequent than right turning pedestrian conflicts, left turning pedestrian interactions produce a number of severe conflicts as shown in **Figure 5**. As left turning vehicles have few available gaps, they often make their turn without first checking for clearance. A number of instances also occur when pedestrians enter the crosswalk near the end of the phase and conflict with late left turning vehicles. Similar conflicts patterns were observed from Camera Location 3, where turning vehicles were in conflicts with late crossing pedestrians. **Figure 6.a** shows the hourly variations in conflicts frequency throughout the day. To further understand the severity of conflicts between pedestrians and turning vehicles, PET is calculated for the detected events (See **Figure 6.b**). PET calculations show the high risk for pedestrians when they are in a conflicting situation with vehicles [7].

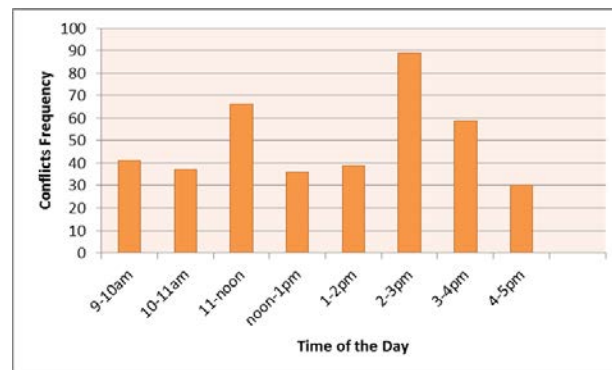
The subsequent step in the safety analysis is to identify violating pedestrians. This is performed by comparing the pedestrian tracks against a given set of prototypes tracks representing standard pedestrian movements' patterns. Any significant disagreement between both sequences of positions is interpreted as evidence that the given track represents the

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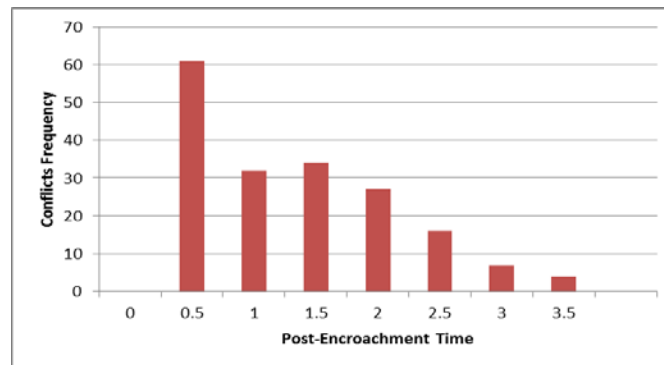
movement of a road user performing a traffic violation. The matching relies on an LCSS similarity measure between the movement prototypes and the trajectories to make decision about the violation detection [11]. Results showed a high level of jaywalking by pedestrians was detected in the mid-block region (33 percent of pedestrians are crossing illegally). As expected, the westbound approach has an increasing number of violations. In fact, according to an earlier study [10] this segment was identified as the highest pedestrian collision-prone area in Greater Vancouver.



Figure 5: Pedestrian-Vehicle Conflicts Frequency Heatmap



(a) Conflicts (with calculable TTC) Frequency Hourly Variation for the Intersection



(b) Distributions of the PET for the combined set of events at the intersection

Figure 6: Conflicts Distributions

Case Study 3: Before-After safety evaluation of right-turn “Smart Channels”

In 2009, the British Columbia Ministry of Transportation and Highways started a pilot project to evaluate the safety performance of Smart Channels. The Smart Channels (**Figure 7**) design has recently been proposed as an alternative right-turn design with a higher level of pedestrian crossing safety. The goal is to reduce the pedestrian crossing distance which can lead to shorter distance exposure, shorter signal cycles, and reduced potential for pedestrians to be in conflict with vehicles. The benefits also extend to vehicle-vehicle interactions since the new approach angle affords drivers a better view of the traffic stream they are to merge with.

Three channelized right-turn lanes in Penticton, BC, were converted to Smart Channels in the summer of 2010. The treatment locations, Duncan, Warren and Green Avenues, are all cross streets to the major thoroughfare, Channel Parkway. At all three locations no dedicated merging lane was provided on the highway; vehicles were required to merge at the end of the channelized right, immediately downstream of the intersection. Turning vehicles were instructed to yield to highway traffic by installed “yield” signage. The realignment treatment, shown in **Figure 7**, decreased the angle of the channelized right between the termination of the right-turn lane and Channel Parkway. The yield signage remained for the right-turn lane.

Data was gathered two days before and two days after at the three locations, as well as at a control site. A control (comparison) site at the intersection of West Bench Hill Road and Eckhardt Avenue was studied in addition to the treatment sites to account for changes in accident causal factors beyond the treatments. The effects observed at the treatment sites were then compared to those at the control site. At the treatment intersections, one camera was used to gather video data of the merging section, while a second camera was focused on the queue of vehicles waiting to turn right.

16th Road Safety on Four Continents Conference Beijing, China 15-17 May 2013



Figure 7: The treatment locations, Duncan, Warren and Green Avenues

Summary of Findings

TTC conflict indicator was used in the study for conflict identification. Comparison is then made with the control site to account for non-treatment conflict causal factors. The intersections of Duncan Avenue and Warren Avenue show consistent improvements between the two intersections: reductions of approximately 75 percent in rear-end conflicts, 45 percent in merging, and 50 percent in total conflicts. Reductions in conflicts at the Green Avenue intersection were less dramatic, ranging from 22 percent to 28 percent (**Figure 8**).

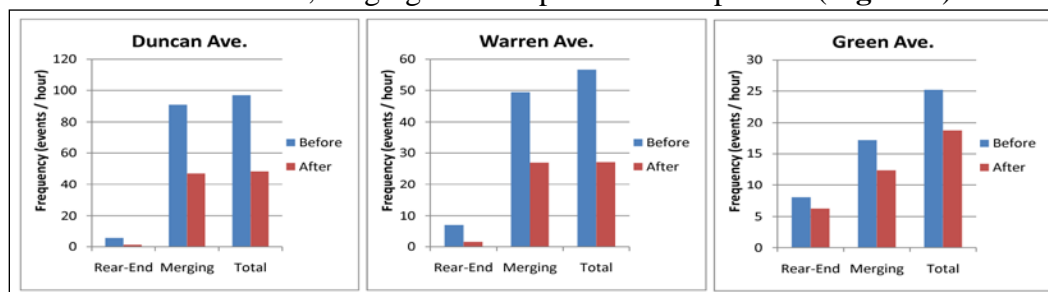


Figure 8: The frequency and cumulative distributions of conflicts at the treated intersection before and after the treatment

In BA traffic safety applications, the conditions pre- and post-treatment at the site are compared to the conditions at a set of control or reference sites over a similar time period. The Treatment Effects for Duncan and Warren Avenues show an AHC reduction of approximately 55 percent for total conflicts. Green Avenue had a Treatment Effect of a reduction in AHC of approximately 35 percent for total conflict types. Over all three treatment sites a reduction of 67 percent, significant at the 90th percentile was observed. Merging and total conflicts were reduced by 48 percent and 51 percent respectively, both significant at the 99th percentile.

16th Road Safety on Four Continents Conference

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The severity of each event can be represented through mapping the minimum time-to-collision (TTC) to a severity index, which ranges from 0 to 1. Total severity is found by summing the severity index of each event and incorporating a measure of exposure [4]. Also, results of conflict severity analysis showed that the intersections of Duncan Avenue and Warren Avenue has decreases in severity in rear-end, merging and total conflict types of approximately 75 percent, 45 percent and 50 percent respectively. The severity decrease at Green Avenue was lower, with a total reduction of 24 percent. The total severity of conflicts, normalized to traffic volumes, was observed to decrease by approximately 41 percent following the treatments. [12]

6 DISCUSSION

This paper presented application of a proactive safety diagnosis procedure where video analysis is employed to automatically identify and analyses serious events such as traffic conflicts and violations. The procedure was applied to the safety analysis of a newly installed bike lane at the entrance of the southern approach of a major Bridge in Vancouver, British Columbia. The results showed a high exposure of bicycles to traffic conflicts. The study also presented potential countermeasures to address the safety issues at the location. The paper also demonstrated the safety evaluation of a location considered to be high risk for pedestrian crossing in Vancouver downtown. The diagnosis identified the safety concerns at this site by locating the most dangerous segments in the intersection. The diagnosis also revealed an estimation of the jaywalking rate at the facility. Generally, two recommendations can be offered at this intersection for improving pedestrian safety. The first includes measures to provide higher level of safety for the crossing pedestrians such as signal changes, construction of pedestrian refuge islands, and potentially prohibiting left turns. The second is increasing the level of enforcement and to reduce pedestrian non-conforming crossing behaviour including jay walking. The experimental results presented in this paper also demonstrated the usefulness of using computer vision techniques for traffic conflicts analyses in BA safety evaluation. The third case study deals with a BA safety evaluation of a newly proposed design for channelized right-turn lanes at intersections. The results of the evaluation show that the implementation of the right-turn treatment has resulted in a considerable reduction in the severity and frequency of merging, rear-end, and total conflicts.

Further development is desired along the analysis procedure. That includes further enhancement and adoption of more accurate road-users tracking and classification. Other developments include the calculation of other severity indicators (e.g., gap-time) to provide more cues for the underlying level of safety of the facility and to set a connection to other safety standard indicators like collision frequency [13]. Future work will also include evaluation of the practicality of the proposed approach can only be achieved through the thorough applications to additional case studies sites.

16th Road Safety on Four Continents Conference
Beijing, China 15-17 May 2013

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