CSCE 2013 General Conference - *Congrès général 2013 de la SCGC*

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

A METHODOLOGY FOR MEASURING THE SEVERITY OF CYCLIST/MOTOR VEHICLE CONFLICTS AT SIGNALIZED INTERSECTIONS

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Abstract: Conflicts between cyclists and motor vehicles at a signalized intersection were characterized using an objective conflict indicator; Post- Encroachment Time (PET). Traffic video data was collected for a total of 28 hours over three days at a signalized intersection in downtown Ottawa. PET was calculated using two analysis methods, manual and automated, for two types of conflicts, right-hook and left-turn. The total number of conflict events analyzed in this study was 119. The results of the conflict analysis show that the average absolute error between the manual and automated PET was 0.23 sec and the standard deviation was 0.29 sec. The results also showed that the average PET using the manual analysis was 1.81 sec with minimum PET 0.43 sec. While the average PET using the automated analysis was 1.73 sec. with minimum PET 0.13 sec. According to the testing and analysis conducted in this paper, the absolute error reflects the efficiency, accuracy and reliability of the tracker system application.

1 Introduction

All road users in traffic might interact with each other while navigating the transportation system. An interaction is defined as “A traffic event with a collision course where interactive behaviour is a precondition to avoid an accident” [1]. The interaction can happen between road users or between road users and the environment. Different types of interaction may happen: [i] negative interactions, e.g., when one of the road users fails to yield to the other and [ii] positive interactions, e.g., when road users observe traffic law. Depending on the nature of the negative interaction, road users may undertake an evasive action. Examples of evasive actions are: swerving, accelerating, decelerating, and emergency stopping. When an evasive action starts late to avoid a collision, there is a possibility for conflict between the road users. A conflict can be defined as “an observable situation in which two or more road users approach each other in space and in time to such an extent that there is a risk of collision if their movements remained unchanged” [2]. The incidence of conflicts is widely recognized as a measure of safety.

The safety of vulnerable road users is becoming a worldwide concern. Cyclists are considered vulnerable road users. When they become familiar with their routes, cyclists may pay less attention to other traffic. For example: on their route to work or school. The incidence of cyclist-vehicle conflict can be regarded as an important parameter in measuring the level of cyclist safety. Conflicts may be considered as a close step to collision. In other words, conflicts can be regarded as events of the same nature and mechanism of action/reaction among road users as road collisions [3]. The severity of conflicts can be partially measured in terms of the proximity to the collision that was avoided.

The incidence of cyclist-involved collisions were investigated in several cycling safety studies at signalized intersections [4], [5], [6] , unsignlaized intersection [7], [8], roundabouts [9], [10], and road-cyclist-path intersections [11], [12].

Hunter *et al.*, [13], and Reynolds *et al.*, [14] define cyclist collision as any contact that occurs between a cyclist and a motor vehicle, pedestrian or another cyclist. Similarly, cyclist-vehicle conflicts can be defined as events during which there was a reasonable chain of events that could lead to a cyclist collision. This chain of events was interrupted at one point by some evasive manoeuvre, *e.g.*, braking, swerving or a combination thereof made by one or more of the conflicting road users.

Various studies in the literature concerned cyclist-vehicle conflicts. Ling and Wu [15], studied the conflict between motor vehicles and cyclists at signalized intersections in Beijing, China. In order to measure the conflict, two times durations were measured from the numbers of photos to calculate Post-Encroachment Time (PET) between the cyclist and motor vehicles. Post-Encroachment Time (PET) can be defined as the time difference between the moment a vehicle leaves as area of potential collision and the moment of arrival of a cyclist to this area while possessing the right of way [16]. The results showed that the average PET was 2.93 sec. and the minimum was 0.52 sec. PET was measured as the difference between the time when vehicle leaves the conflict point and the time when the front wheel of the cyclist arrives at the conflict point.

Sayed *et al*., [17], studied the conflict between motor vehicle and cyclist at Burrard Bridge in Vancouver, Canada. Video data was used and a video- based computer vision technique was applied. In order to measure the conflict between motor vehicle and cyclist, a Time to Collision (TTC) was used. TTC is defined as "the time that remains until a collision between two vehicles would have occurred if the collision course and speed difference are maintained" [18]. The results showed high percentages of cyclists exposed to traffic conflicts.

The objective of this paper is to investigate the potential of measuring PET between cyclist and motor vehicle from automated video analysis using computer vision techniques. In this study, PET was defined as the time difference between the moment of a rear vehicle leaves, or front vehicle arrives at, the area of potential collision and the moment of arrival to, or departure of a cyclist from, this area while possessing the right of way. Depending on the context of the joint cyclist and motor vehicle movements, different patterns of conflicts may occur. Conflict types considered in this study are right-hook conflicts and left-turn conflicts. Right- hook conflict is defined as a motor vehicle making a right turn, and suddenly crossing the cycle path while the cyclist moving straight [19]. Left-turning vehicles may collide with a through-moving cyclist while crossing the intersection in opposing direction. Figure (1) illustrates the two conflict types.

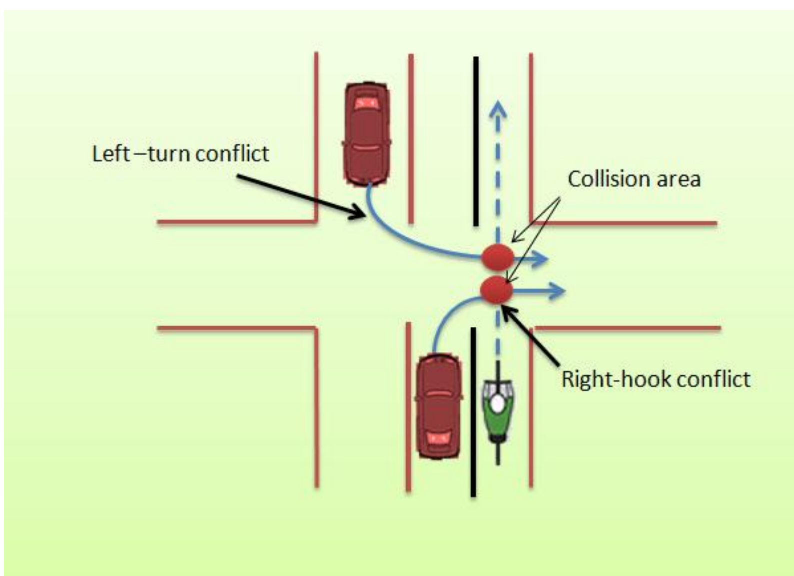

Figure 1: Schematic Diagram: Right-hook and Left-turn Conflicts.

2 Data Collection

For the purpose of studying PET between cyclist and motor vehicle, a video camera was used to monitor cyclist and motor vehicle movements. The camera was placed at a height of 15 floors in a building overlooking the four-leg signalized intersection at Laurier and Lyon streets, located in downtown Ottawa. Data was collected in July 2012 over three days. A total of 1034 cyclists was observed as a measure of the exposure. A view of the location of the intersection as seen by the camera is given in Figure (2).

Figure 2: Site location and camera position [20].

3 Video Analysis

In this section, video data analysis methods are classified as: manual analysis and automated analysis. The two methods are described in the following subsections.

3.1 Manual Analysis

Manual review was used in order to classify the behaviour of the cyclists and motor vehicles while crossing the signalized intersection. Two types of conflict were observed at the study area: right-hook and left-turn conflicts. Four different scenarios were used in order to detect the interaction type at the potential collision area depending on the vehicle's turning movement and which road user arrives at the possible collision point first as shown in Figure (3). Three different levels of conflict severity between cyclists and motor vehicles were used: low, moderate, and high. In order to objectively classify conflict severity, a PET range was used for each severity level.

As defined earlier, PET is the time difference between the moment when the rear end of a motor vehicle leaves an area of potential collision and the moment of a cyclist arrival to this area. The time difference between the moment of a cyclist leaves an area of potential collision and the moment of a front motor vehicle arrives to this area. A threshold of 3 seconds was used as to detect a conflict. When the time difference between cyclist and motor vehicle is less than 1 second, the conflict severity level is classified as high. When the time difference between a cyclist and a motor vehicle is between 1 and 2 seconds, the conflict severity level is classified as moderate. When the time difference between a cyclist and a motor vehicle is greater than 2 second and less than 3 second, the conflict severity level is classified as a low.

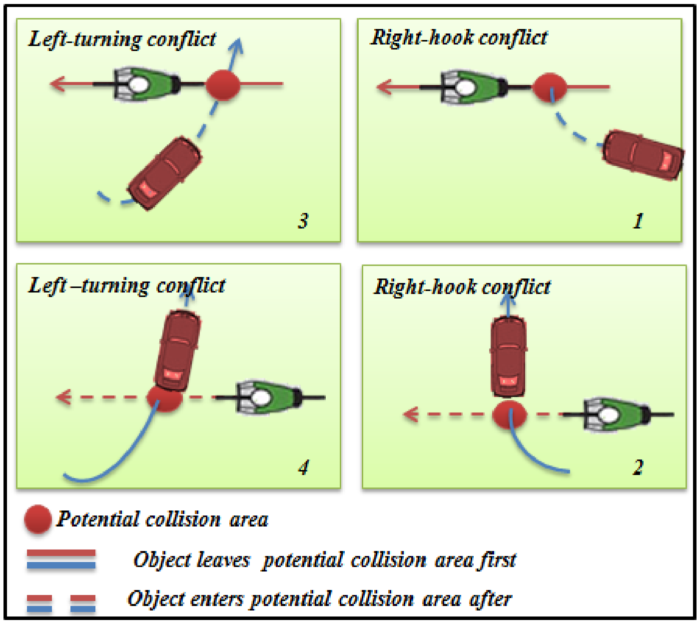

Figure 3: Cyclist-motor vehicle conflict scenarios.

3.2 Automated Analysis

The automated video analysis of cyclist-vehicle conflicts uses a 2D projection of both the vehicle and cyclist on the camera plane. Therefore, four corners of the conflict vehicle in this 2D projection were used to determine the PET between the cyclist and motor vehicle. These corners are: top-right, top-left, bottom-right, and bottom-left (as shorthand will be denoted TR, TL, BR, and BL, respectively). These corners were identified by a boundary box containing all moving features detected by the tracking system as shown in figure (4). The tracker system is an improved version of an open-source feature-based vehicle tracking system [21], [22], [23], [24] and [25]. For each corner a corresponding PET is calculated. The duration of PET equals the difference in time between the four corners of a conflict vehicle with the right or left end of a bicycle. However, the automated analysis used only the bottom-center of the bicycle for estimating PET, with an adjustment for the bicycle dimensions. Adjustments were made for the PET in order to correct for systematic error due to neglecting the dimension of a cyclist. When a cyclist leaves an area of potential collision first with left-turning conflict type, the back wheel of the cyclist is closer than the center-bottom to the TR of the conflict vehicle. Therefore time was calculated equivalent to the half of the cyclist length. The time equals half of the cyclist's length divided by cyclist's speed. The cyclist's speed was calculated at the area of potential collision. The adjustment PET equals the tracker system PET minus the time equivalent to the half of the cyclist length. Adjustments were made for the PET for each corner of conflict vehicle. The time is the number of frames multiplied by the frame rate of 30 frames/sec. When a cyclist leaves an area of potential collision first with left-turning conflict type, the PET of TR was used as closest corner to the cyclist at potential area of collision. PET of BR was used when a conflict vehicle leaves an area of potential collision first with left-turning conflict type. PET of TL was used when a conflict vehicle enters an area of potential collision after cyclist leaves with right-hook conflict type. Finally, PET of BR was used when a conflict vehicle leaves an area of potential collision first with right-hook conflict type.

The tracker system is considered as more reliable and accurate tool compared to the manual review analysis. The tracker system keeps track of every moving object in the video in terms of x and y frame by frame. Each object is being tracked with a boundary box containing all moving features detected by the tracking system. All object positions were calculated based on precisely laid out mathematical equations. The tracker system computes the intersection point by finding the shortest distance between two positions of two different objects. While the manual review was estimated for the conflict points depending on the reviewer's judgment. The tracker system provides the user the facility to choose what the desired position to be drawn in the visualization. In addition the tracker system makes it easier for the user to obtain the accurate value of PET.

A summary of the algorithm for calculating PET:

1- Calculate the shortest distance between each of four corners of conflict vehicle and center bottom of cyclist.
2- Both ends of the shortest distance formulated the intersection point between vehicle and cyclist.
3- Locate the frame at which the intersection occurred for vehicle and cyclist.
4- Find the total number of frames taken for both vehicle and cyclist to reach the intersection point.
5- Total frames taken= frame at the intersection + first frame at which the object started.
6- Calculate the time for both vehicle and cyclist to reach the conflict point by multiplying number of frames times 30 (frame rate 30 frames/sec).
7- Calculate PET:
   7-1 if cyclist time is greater than vehicle time, then PET = cyclist time - vehicle time.
   7-2 if vehicle time is greater than cyclist time, then PET = vehicle time - cyclist time.

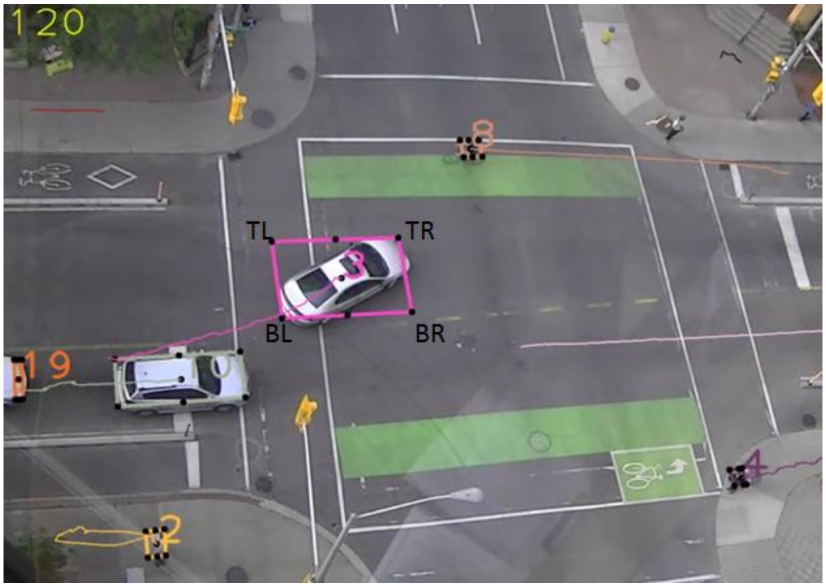

Figure 4: Conflict vehicle corners identified by tracker system.

3.3 Camera Calibration

In order to conduct metric measurements, the recording camera is calibrated by knowledge of geometric primitives that appear in the video and their corresponding appearance in an orthographic image of the intersection. Also, field measurements were made to establish the true lengths of segments that appear in the video in order to aid the calibration process. The field measurements, parallel lines in real world image, camera position, center and origin of the frame were taken to correspond to the orthogonal image taken of the same intersection, camera height, and a frame taken from the video were considered as input data to a camera calibration approach [26]. Figure (5) illustrates linear segments that were taken as measurements required to determine the camera calibration, orthographic grid, and world-wide grid.

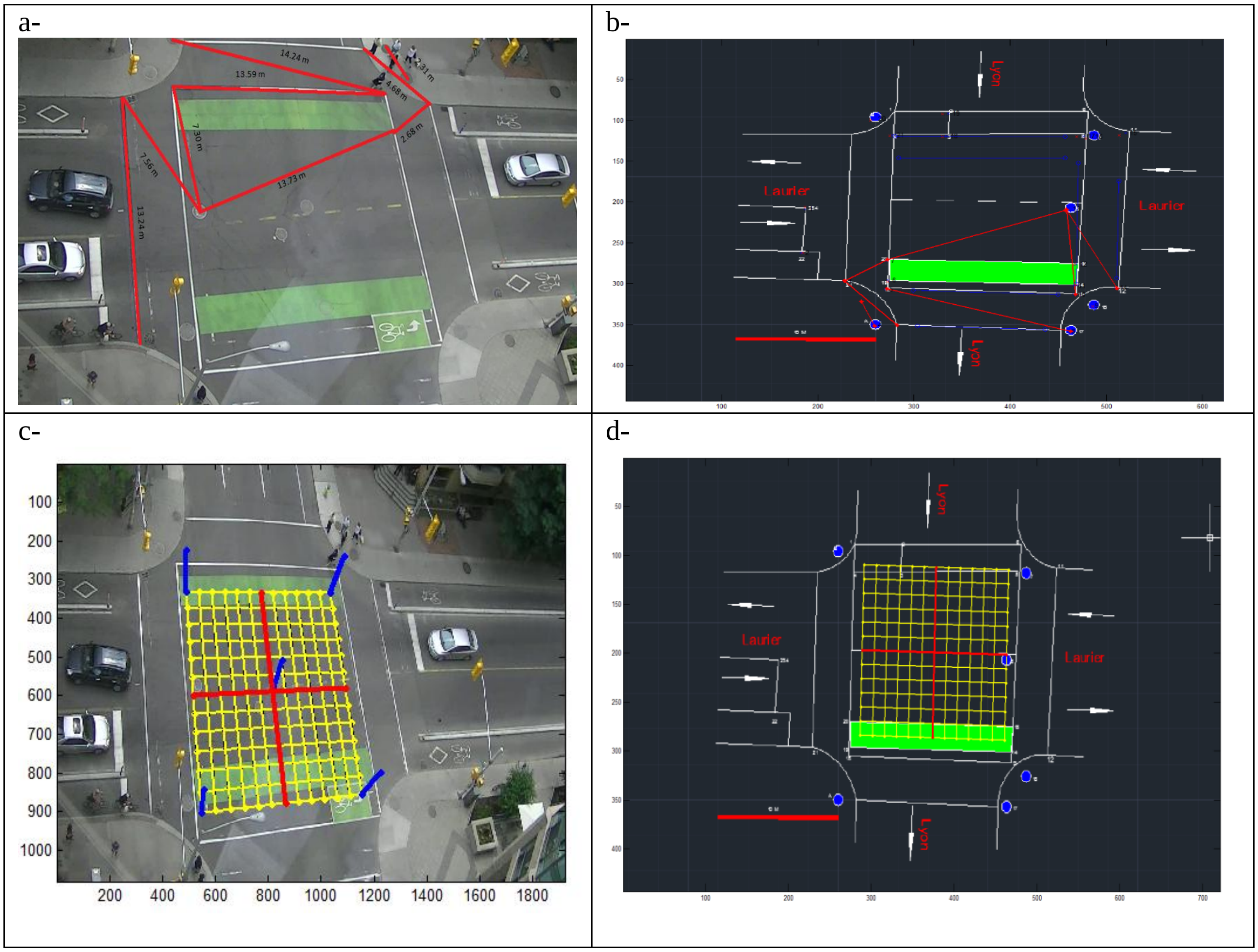

Figure 5: a- Field distance measurements, b- Projected distance using camera calibration, c- Orthographic grid, and d- World-wide grid at the area of study (signalized intersection at Laurier and Lyon streets).

4 Discussion of the Results

A total of 119 conflict events were recorded in both the manual and automated analyses. A summary of the results of the conflict severity level classification between cyclist and motor vehicle for these conflict events is shown in Table 1. PET was calculated between the center bottom of a cyclist and the four corners of a conflict vehicle.

Table 1: Manual and automated conflict severity level classification.

Analysis Type	Conflict Severity Levels		
	Total Number of Low Severity	Total Number of Moderate Severity	Total Number of High Severity
Manual	40	68	11
Automated	36	72	11

Figure (6) shows the relationship between the conflict severity levels that were obtained manually and the PET that was obtained by the tracker system. The average absolute error in PET was found 0.23 sec. and the standard deviation of absolute error in PET was found 0.29 sec. The error is the difference between manual and tracker PET. Figure (7) illustrates the variation changes between the boundary box conflict corners of conflict vehicle and the error of PET.

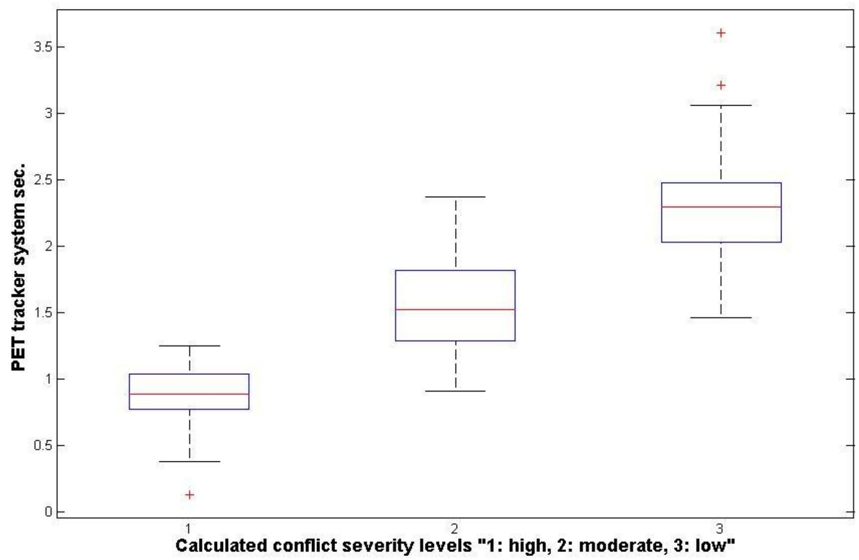

Figure 6: Relationship between manual calculated severity levels and tracker system PET.

Figure.6 shows the median of high and moderate conflict severity levels near to the center of the box, the distribution is approximately symmetric. While the median of low conflict severity level is above the center of the box, the distribution is negatively skewed. At the high conflict severity level shows that a substantial proportion of the data is on median. The median of high conflict severity level is approximately less than 1 sec. For the moderate conflict severity level, the median is located around 1.5 sec. For the low conflict severity level, the median is located close to the 2.5 sec. The outliers' points refer to the PET values that were obtained by the tracker system.

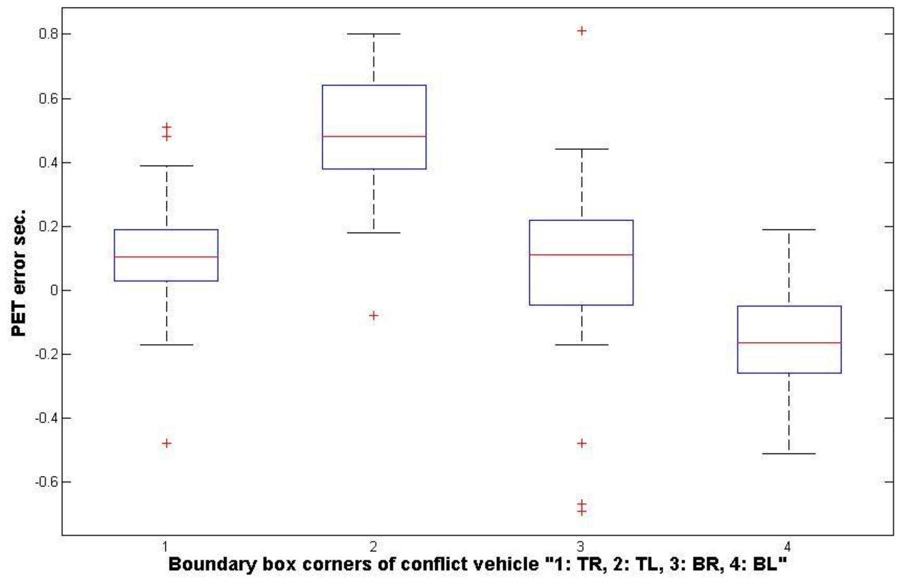

Figure 7: Variation Changes between boundary box conflict corners and the PET error.

Figure.7 shows the median of TR and BL corners of conflict vehicle near to the center of the box, the distribution is approximately symmetric. The median of TL corner of conflict vehicle is under the center of the box, the distribution is positively skewed. While the median of BR corner of conflict vehicle is above the center of the box, the distribution is negatively skewed. That means many valuable data is high. At the TR corner of conflict vehicle shows that a substantial proportion of the data is on median. The median of TR is located at 0.1 sec. For the TL corner of conflict vehicle, the median is close to 0.5 sec. For the BR corner of conflict vehicle, the median is located at 0.1 sec. For the BL corner of conflict vehicle, the median is located close to -0.2 sec.

5 Conclusions

This paper presents a reliable video analysis technique to measure the Post-Encroachment Time between cyclists and motor vehicles. Two different analyses were performed. In the manual review analysis the numbers of low, moderate, and high conflict severity were 40, 68 and 11 respectively. While using the tracker system “automated analysis” the numbers of low, moderate, and high were 36, 72 and 11 respectively. In the manual review analysis the last /or first corner of a conflict vehicle that leaves an area of potential collision was used to measure the PET. This corner may not be a closest part of a conflict vehicle to a cyclist. The conflict point was merely estimated in the manual review analysis. The average absolute error was found 0.23 sec. and the standard deviation was found 0.29 sec. The results also showed that the average PET using the manual review analysis was 1.81 sec. with minimum PET 0.43 sec. While the average PET using the automated analysis was 1.73 sec. with minimum PET 0.13 sec. According to the testing and analysis conducted in this paper, the absolute error reflects the efficiency, accuracy and reliability of the tracker system application. Further improvement can be made to the tracker system such as providing an automated mode where the most accurate position is calculated without manual selection. This provides a major benefit in terms of saving time compared to the manual selection. In addition the tracker system decreases the probability of human errors. To the authors’ knowledge, this is a unique study in terms of the automated video analysis approach used to measure PET between motor vehicle and cyclist.

Acknowledgments

This research was supported by grants from the Ministry of Transportation of Ontario (MTO) through the Highway Infrastructure and Innovation Funding Program (HIIFP), the City of Ottawa, and the Natural Science and Engineering Research Council of Canada (NSERC) through the Discovery Grant (402200-2011) of the second author.
The authors thank Munther Hussain for his contribution of tracker development.

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