

Analysis of Left-Turning Vehicles at a 4-way Medium-Sized Signalized Intersection

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ABSTRACT

This paper presents path geometries, velocities and accelerations of left-turning vehicles for one particular intersection layout. Video footage was taken above a typical urban intersection to record vehicles making left turns. The vehicle trajectories were analyzed to evaluate position, velocity and acceleration. In addition to recording whether vehicles stopped before making their left turns, the initial vehicle headings, vehicle types, traffic signal status, and destination lanes were tracked. For each travel direction, the path geometry data was analyzed to identify an average turning radius for the left turns and an average pull-out distance for vehicles that stopped before turning.

INTRODUCTION

In 2007, about 21% of all traffic fatalities in the U.S. were intersection related [1]. A similar statistic was reported for 2002 where it was also described that 50% of all motor vehicle crashes occurred at intersections [2]. Specifically, many collisions occur when a left-turning vehicle crosses the path of an oncoming vehicle at an intersection. In Alberta, Canada, left turn across path scenarios were the third highest improper driver action leading to a casualty collision and accounted for 13% of all casualty collisions in 2007 [3].

Usually, there are few collision-related roadway markings or tire marks to verify the path taken by a left-turning vehicle, particularly in urban areas where speed limits are lower. In these cases, it can be difficult to identify the point of impact and, frequently, quantify the impact speed of the left-turning vehicle. This makes it challenging to evaluate the time lapsed from the start of the vehicle's turn and relative pre-collision vehicle

positions. As such, in order to fully reconstruct the collision and prior events, assumptions have to be made with respect to the path taken by the left-turning vehicle and the dynamics of the vehicle as it made its turn (e.g. where did the vehicle stop, how did it accelerate, etc.). These assumptions can be somewhat subjective and differing approaches can affect the results of a reconstruction. There is a need for real world documentation of left-turning vehicles.

In order to obtain empirical data of unaware drivers making left turns, a four-way intersection within a medium sized Canadian city (population of about 1 million) was videotaped. The video footage was taken from high above the intersection to record vehicles making left turns from all four directions. The intersection was surveyed and the resulting video was analyzed with point tracking software to record the vehicle trajectories. Each videotaped vehicle had its path manually identified in the software, which then outputted tabular trajectory data. A two-dimensional analytical rectification method was used to correct the outputted vehicle trajectory data in order to compensate for the camera's slight offset and non-orthogonal position to the road surface.

A summary of all the vehicles monitored during the testing will be presented. Also, overviews of their path geometries, path radii, mean velocities, maximum velocities, mean acceleration rates and maximum acceleration rates will be discussed. Derived statistical measures are also presented, which can be used to describe a left-turning vehicle's path and dynamics for the type of intersection monitored in this study. Although this paper examines only one intersection (geometry, speed limit etc.), the approach followed for this project could be used to evaluate other intersection types and create a library to address many left-turning situations.

LITERATURE REVIEW

A review of previous literature was conducted to determine whether there was existing data that described how vehicles made left turns at intersections. It was found that various published studies and articles have addressed factors such as acceptance gap, sight distance and intersection geometry. However, there were no studies found that specifically addressed the path geometry for left-turning vehicles at an intersection. Furthermore, there were no found studies that examine this path geometry in conjunction with the vehicle speed and acceleration through that path. Nonetheless, some success was encountered with the discovery of a few papers that specifically reported acceleration rates or velocities of vehicles in intersections.

A recent study by Classen, et al. [4] examined the differences in driver performance between young drivers and older drivers at *improved* and *unimproved* intersections. Test subjects drove through a course with several different intersection configurations and their performance was evaluated. For the intersections used in the experiment which required a left turn by the driver, maximum longitudinal acceleration factors were reported to range between 0.11 g and 0.21 g. The lower end of the range represented vehicles that did not come to a stop before conducting the turn. Maximum speed values for the turns were also reported and varied between 6.20 m/s (22.3 km/h) and 9.75 m/s (35.1 km/h) depending on the intersection configuration and the age group of the drivers. Although some of the data presented may be useful for accident reconstruction purposes, the study did not track the vehicle path during any of the left turns.

Fugger, et al. [5] examined driver perception-response times and vehicle acceleration rates from a real-world intersection. The vehicles in this study were travelling a straight path through the intersection rather than making left turns. Interestingly, Fugger's study utilized video analysis for tracking the vehicle motion through the intersection and the results indicated that acceleration for passenger vehicles consisted of two distinct phases. The initial phase of acceleration for all vehicles in the study was observed to occur over a time period of 0.94 sec (+/- 0.48 sec) and the rate over this initial phase was determined to be 0.06 +/- 0.03 g. The secondary phase of acceleration was found to be 0.22 +/- 0.05 g.

A study by Muttart [6] also presented acceleration rates, but the documented vehicles in this study were making left turns. Muttart marked off a fixed distance of 12 m (40 ft) and examined different classes of vehicles making left turns as they travelled a "*typical path*" over this distance onto a roadway. Although the precise path geometries of the sampled vehicles were not recorded, the vehicles were timed and average acceleration rates of the vehicles were calculated over the fixed distance assuming that vehicles were initially stationary. Observed vehicle acceleration factors for automobiles and light trucks were reported as being 0.277 g and

0.290 g, respectively. Since many of the vehicles had not been at rest prior to the measured distance, the reported acceleration rates were higher than what the vehicles actually would have experienced.

TEST PROCEDURE

The particular intersection selected for the study was chosen based upon its geometry (having multiple lanes of traffic in each direction), moderate traffic flow, and an open view from an overhead vantage point. Ideally, this vantage point would have been directly above the center of the intersection, so that any recorded movement collected from video tracking software would not have to be corrected. However, this positioning was unattainable and, instead, the intersection was monitored from a tall office building, with efforts made to reduce the error introduced by the offset and non-orthogonal orientation of the camera.

Vehicles at this intersection were able to make left turns from all four directions. The intersection was oriented with all the directions aligned nominally north, south, east and west. Northbound and southbound traffic had three through lanes with no dedicated left-turn lanes. Eastbound and westbound traffic each had a dedicated left-turn lane and two through lanes. Figure 1 illustrates the layout of the intersection based upon a total station survey of the intersection.

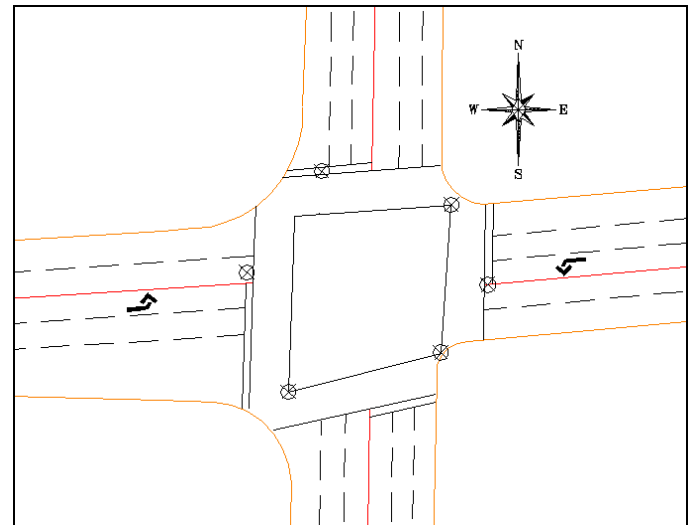


Figure 1 – Test intersection geometry and locations of control points.

The intersection was situated within a downtown core of a medium sized (~ 1 million people) Canadian city. The speed limit was 50 km/h for all directions of traffic. There were office buildings situated along both sides of each roadway with sidewalks for pedestrian traffic. Traffic lanes were delineated with painted lines and there were no raised medians. There were painted stop lines for each of the four traffic directions. Painted crosswalk lines also bordered the perimeter of the intersection to identify pedestrian crosswalks.



The intersection was controlled by overhead traffic signal lights for all four directions of travel. The timing of the traffic signals was based on set time frames and was not variable based upon traffic demand. At the time that vehicles were being recorded, there were two light timing sequences active. The first sequence provided left-turn advance green signals for both southbound and eastbound traffic. The second timing sequence provided only a southbound advance green, as the eastbound advance green was deactivated.

A large office tower adjacent to the intersection served as a base in which to set up the video camera. A Canon XH A1 High Definition digital video camera was used to record the intersection from a tripod on the 25th floor placed close to an exterior window that faced the roadway. From this vantage point, the entire intersection was visible, as well as the approaches in the north and south directions. However, due to obstructions, the view of eastbound and westbound approaches was more limited. Figure 2 shows a still image of the footage taken from the elevated vantage point and how the side of the office tower and other buildings provided limited views of the approaches to the intersection.

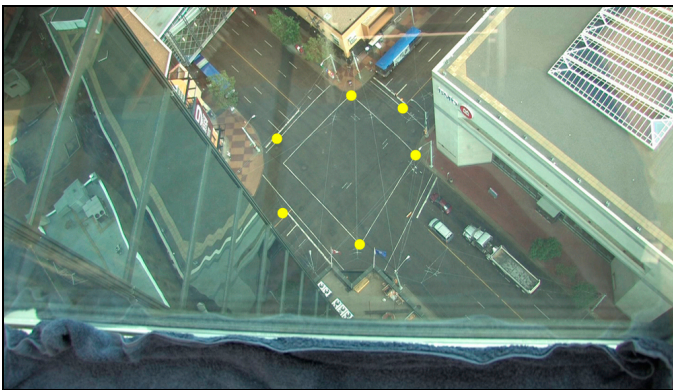


Figure 2 – Video still image of test intersection showing control point locations.

Video recording was conducted over approximately four hours on the morning of July 16, 2008, between 8:00 a.m. and noon. The weather was cloudy and there was a light rain falling. Traffic density varied from light to moderate. In preparation for the recording, several control points were marked on the road surface. The locations of the control points and the general intersection geometry were surveyed using a total station. Figures 1 and 2 show the locations of the control points that were used for the two-dimensional analytical path correction procedure.

In order to verify the method of using the point tracking software for tracking vehicle paths and applying a two-dimensional analytical rectification, an instrumented vehicle was driven through the intersection from all four directions during the study. A 2006 GMC Canyon pickup truck was instrumented with two single-axis Piezotronic accelerometers. These accelerometers were mounted orthogonally, with their positive axes facing

forward and to the left, on a mounting block that was rigidly attached to the vehicle and visible from above. The mounting block was situated along the vehicle's mid-line above the rear axle at an elevation of 1.27 m.

The longitudinal and lateral accelerations of the instrumented vehicle were captured at 125 Hz for each of four test runs where the truck was driven through a left turn from each of the four directions. These recorded accelerations captured not only the tangential and normal acceleration components in each turn, but also the effects of any roll or pitch.

DATA ANALYSIS

The recorded digital video was analyzed using VideoPoint, a commercial software program supplied by Lenox Softworks, to track the positions in time of the left-turning vehicles in the intersection. The software utilizes a cross-hair selection method that allows the user to track an object frame-by-frame. The software then outputs the time and (x,y) co-ordinates of that point in the co-ordinate system of the camera's view.

For this study, a two-hour time frame of the recorded intersection was scrutinized. As the footage was analyzed, every vehicle that approached the intersection to make a left turn was assessed. However, vehicles that were following directly behind other vehicles as they made their left turns were not tracked because it was felt that their turns may have been influenced by the vehicle in front. Overall, the paths of 202 left-turning vehicles were tracked with the software. On each vehicle, a distinguishable point along the vehicle's mid-line and coincident with the top of the windshield (or the leading edge of the roof) was chosen throughout the vehicle's turn. This point was chosen in order to be a close approximation of the location of a vehicle's center of gravity and to be consistent from vehicle to vehicle. Figure 3 shows a sample screen from the video tracking software and a point selected on a left-turning vehicle.

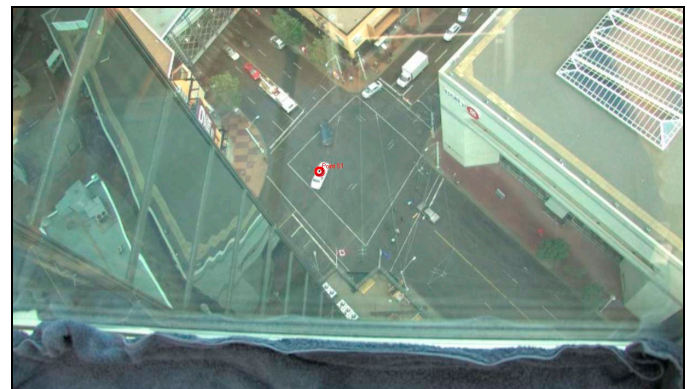


Figure 3 – Sample point tracking of vehicle.

Although the video recording had captured the images at approximately 30 frames per second, the markers on the vehicles were not identified for each frame. The reason for this approach was that the change in a vehicle's position

vehicles' position on a frame-by-frame basis was relatively small. For example, at a speed of 20 km/h, the vehicle would only move approximately 0.2 m in 1/30 second. This corresponded to a distance of about one pixel width, which was approximately 0.15 m. At lower speeds, the distance traveled between frames was even smaller. Also, when vehicles came to a stop, there was no need to track stationary points. As such, vehicle motion was tracked approximately every third frame (i.e. every 0.1 sec) and at the transition of any halted motion.

Since the video camera was not pointed straight down at the relatively flat intersection, the generated pixel co-ordinates did not represent correct absolute positions of the tracked vehicles. In order to convert these pixel co-ordinates of the vehicle paths into absolute position co-ordinates relative to the real world, a two-dimensional analytical rectification procedure was applied to the exported vehicle path co-ordinates. This method was applied to the vehicle paths since the intersection was flat and it could be assumed that the tracked points for a single vehicle lie in the same plane. The method of rectification used in this study is common and has been described by several authors including Kerkhoff [7] and Wolf [8].

The applied method required the absolute co-ordinates (X,Y) of four known control points to evaluate the constants of the following two equations:

$$X = \frac{a_1x + b_1y + c_1}{a_3x + b_3y + 1} \quad (1)$$

$$Y = \frac{a_2x + b_2y + c_2}{a_3x + b_3y + 1} \quad (2)$$

The control points at the test site were surveyed to determine their absolute positions on the roadway plane. These points were also tracked in the VideoPoint software, providing (x,y) pixel co-ordinates. However, since the elevations of the tracked points on the vehicles were on their roofs, above the road surface, the control points could not be selected on the road surface. A surveying prism pole was set to an elevation of 1.55 m to approximate the average height of the tracked vehicles and the prism was selected in VideoPoint at each of the control points. This provided control points in approximately the same plane as the tracked vehicle points. A transformation matrix was then created using Equations 1 and 2 that was applied to the tracked vehicle paths.

A sensitivity analysis was conducted to evaluate the influence of applying a transformation matrix based on a 1.55 m average height for all recorded vehicles. Considering the full range in height of cars, vans and trucks that would have been tracked, the maximum error that would have been induced by this assumption was that the entire vehicle path would be offset by up to 9 cm. Only the absolute location of the path on the roadway would be affected and not the curvature of the

path. This maximum 9 cm position error was within the range of uncertainty associated with selecting pixels in the video for a vehicle's path, which was 0.15 m.

For the four test runs with the instrumented GMC Canyon, a different transformation matrix was applied. In VideoPoint, the test vehicle was tracked at the accelerometers' mounting location rather than at the approximate center of mass. In addition, control points were measured at 1.27 m, the elevation of the mounted accelerometers.

For each documented vehicle, several other parameters were recorded in addition to the tracked path. These included:

- Path Direction – Turning vehicles were grouped according to what direction they were initially heading: north, south, east or west.
- Vehicle Type – The vehicles were classified into one of three types: passenger car, sport utility vehicle (SUV)/van, pickup truck. SUV's and vans were grouped together as they are similar in appearance when viewed from above. Large commercial vehicles and transit buses were not recorded.
- Traffic Signal – The status of the traffic light was determined from review of the traffic patterns in the video and the traffic light timing sequence provided by the local municipality. The three different stages for the left-turning vehicles included green, advance green and amber.
- Stop Before Turn – It was noted whether the vehicles stopped before making their turn. If the vehicle stopped, the distance from the stop line to the vehicle's stopped position was also documented.
- Oncoming Vehicles – If an oncoming vehicle was observed approaching the intersection after the tracked vehicle had cleared the oncoming vehicle's path, then the distance of the oncoming vehicle from the stop line was noted.
- Destination Lane - The lane into which each vehicle ended up in after the turn was identified with respect to the lane positions in the intended direction of travel. There were seven possible locations for a vehicle's center of mass after its turn was completed: lane left of centerline, on centerline, lane right of centerline, first dashed line, second lane right of centerline, second dashed line and third lane right of centerline.

The general path of each vehicle consisted of a straight trajectory from the initial direction of travel followed by a