Post impact trajectory of vehicles at rural intersections

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Abstract

This report describes the path of vehicles after a collision with another vehicle at a rural intersection. The information was obtained from in-depth investigations of 70 intersection crashes. For ease of analysis, both rear end crashes and collisions involving vulnerable road users were excluded; heavy vehicles were included. The vehicle that had right of way most commonly had an impact speed of between 80 and 99 km/h and the impact point was on the front of the vehicle. The vehicle that was required to give way most commonly had an impact speed of between zero and 20 km/h and was struck between the front of the vehicle and the B-pillar. After the vehicle-to-vehicle impact, half the vehicles travelled more than 18 metres, 20% more than 34 metres and 10% more than 50 metres from the centre of the intersection. The most common direction of the vehicle following the initial impact was found to be between 15 and 30 degrees, from the original direction of travel of the through vehicle. Intersection geometry, speed zone, impact point and mass ratio influence the nature of the post impact trajectory. The results show that many vehicles travel a large distance at a shallow angle following an intersection collision, so extending a barrier on the through road (the road with right of way) up to the intersection may have some benefit. Clear zones surrounding the intersection would aid in creating a safe system providing they are of adequate size. Removing hazards around an intersection would have the added benefit of increasing site distance.

Introduction

This paper describes the path of vehicles after a collision with another vehicle at a rural intersection. The aim was to provide guidance to transport authorities on roadside design at intersections. This research was prompted by observations during CASR's in-depth crash investigations that demonstrated that it is possible for a vehicle to strike a roadside hazard following a collision with another vehicle, and that this secondary impact can be more severe than the initial vehicle-to-vehicle collision.

The current Australian guidelines for road design, first published in 2009, are not explicit on roadside design at intersections to protect vehicles from secondary impacts with roadside objects. The Austroads Guide to Road Design Part 4 [1] briefly mentions that adequate clear zones should be provided around intersections because a significant number of off-road crashes occur at intersections. The reader is referred to the Austroads Guide to Road Design Part 6 [2], although this document makes no specific mention of clear zone requirements at intersections. It is therefore inferred that Austroads intended clear zones to be applied in the same manner at intersections as it recommends for mid-block sections of road. However, Austroads [2] states that the clear zone widths it recommends are only applicable to low angle departures. This suggests that different clear zone guidelines may be warranted at intersections as high departure angles are possible following a vehicle to vehicle collision.

A search of the literature found no prior research of this nature. The majority of research into intersection crashes focuses on the pre-crash movements of the vehicles rather than the movement of the vehicle after the initial impact. Only one study was found that made reference to post impact trajectory of vehicles following an intersection crash. This study examined metropolitan crashes and found that 15 vehicles from a sample of 35 uncontrolled intersection crashes struck a roadside object after the initial collision [3].

Method

Detailed information concerning high speed rural road intersection crashes was obtained from the Centre for Automotive Research's (CASR) in-depth crash investigation database. The database consists of information collected through the in-depth investigation of crashes in which any crash participant is transported by ambulance to hospital, or suffers fatal injuries.

Rural road crashes were investigated by CASR during two separate time periods; 1998 to 2000 and 2006 to 2010. For this study, crashes involving a vehicle-to-vehicle collision at a rural junction were identified from both time periods. The study focussed on impacts between vehicles travelling in different directions therefore rear end crashes were excluded. Vulnerable road users such as motorcyclists, cyclists and pedestrians were excluded to simplify the interpretation of outcomes. Heavy vehicles, however, were included in the study. In total, 40 intersection crashes were obtained from the period of 1998 to 2000, and 30 for the period of 2006 to 2010.

There were four types of collisions identified as shown in Figure 1. Note that the use of a cross road is for illustration purposes and that crashes at T-intersection type intersections were also considered. In all four collision types, one vehicle (designated unit 1) was travelling through the intersection with right of way, at which point a second vehicle (designated unit 2) entered the intersection and a collision occurred. In all cases, unit 2 disobeyed either a direct indication to yield (give way / stop sign), or an implied direction (give way to the right). The description used for the various configurations is based on the movement of the vehicle that was required to give way.

In order to analyse the four collisions types together x and y directions were nominated for each. The positive x direction is matched to the direction of travel of unit 1, as seen in Figure 1. The positive y direction is matched to the initial direction of unit 2 in all but the right turn (off) type, in which the positive y direction is matched to unit 2's intended direction of travel. Note that the straight and right turn (on) configurations may also occur with unit 1 in the lane closest to unit 2 (travelling from right to left). In this case the positive x direction shown in the diagrams would point from right to left as well so as to match the direction of travel of unit 1.

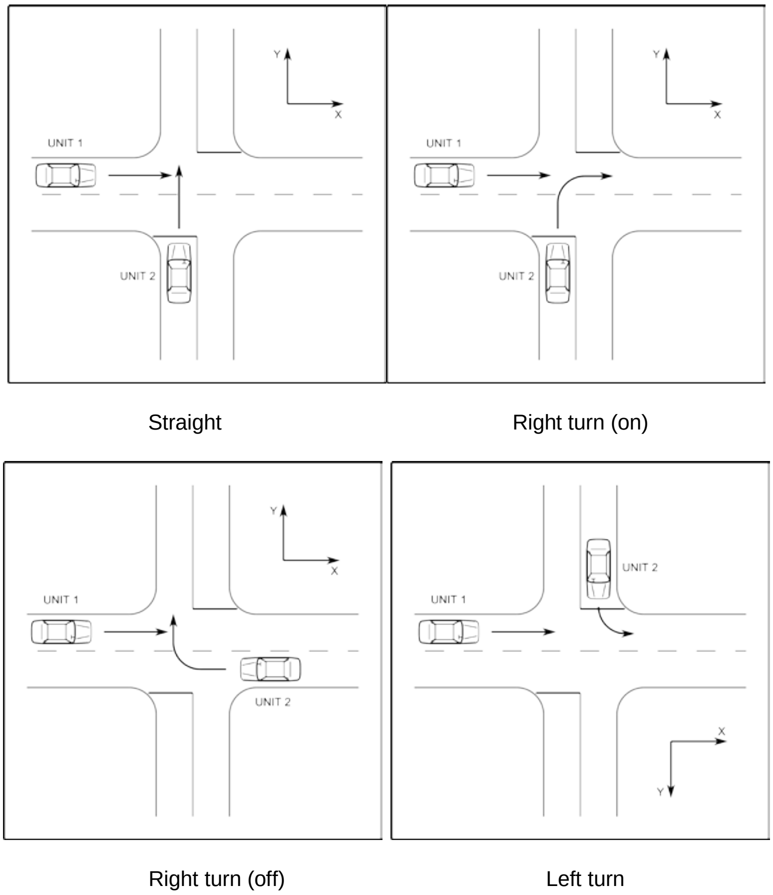

Figure 1. Intersection collision types included in the study
Note: Straight and right turn (on) crashes may also occur with unit 1 in the near traffic lane. In these cases the positive x-direction would be left to match unit 1's direction of travel.

Variables describing the intersection, crash and vehicle characteristics were obtained from the database. The crash and crash location variables noted were;

- Road geometry (e.g. cross road)
- Traffic control (e.g. give way sign)
- Most severe impact (vehicle-to-vehicle or vehicle-to-roadside object)
- Collision type (see Figure 1)

The unit-based variables were;

- speed limit
- impact point (e.g. between the A and B pillar
- struck object (if any)
- vehicle mass
- injury severity (the highest level of injury in that unit)
- x distance (see Figure 2)
- y distance (see Figure 2)
- straight line distance (the length of a direct line from the centre of the intersection to the furthest point of the vehicles final position as shown in Figure 2)
- angle (The angle between the x axis and the line created by the straight line distance)

The geometric unit based variables are shown diagrammatically in Figure 2.

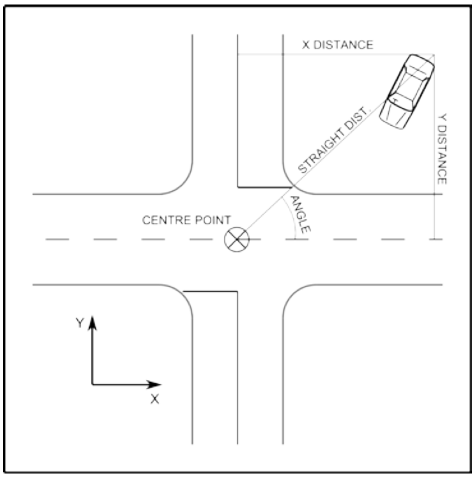

Figure 2: Measurement of post impact trajectory

Results

The majority of the in-depth crashes examined involved were either straight or right turn (on) collisions. There were marginally more cross roads than T-junctions. No form of traffic control was found at almost half the intersections. Give way signs were reasonably common but stop signs were present at less than a fifth of the intersections at which crashes occurred (Table 1).

Table 1: Characteristics of the rural intersection crashes

Collision type	Number	Percentage
Straight	28	40.0%
Right turn (on)	30	42.9%
Right turn (off)	11	15.7%
Left turn	1	1.4%
Intersection geometry		
Cross road	37	52.9%
T-junction	33	47.1%
Traffic control		
None	32	45.7%
Give way sign	26	37.1%
Stop sign	12	17.1%

The occupants of vehicles classified as unit 2 (the vehicle which had to give way) had a much greater chance of being fatally injured, however no account was made for the fragility of car occupants. A vehicle occupant requiring, at worst, hospital treatment was the most likely outcome for either unit, although marginally so for unit 2. This is not surprising given the criterion of ambulance transport for a crash to be included in the in-depth crash investigations.

The most severe impact was almost always the collision between vehicles, although on three occasions the most severe impact was a secondary collision with a roadside hazard. The characteristics of these three crashes are outlined below;

- Two of the vehicles struck a stobie pole, one struck a tree
- All involved a side impact configuration
- One vehicle had also begun to rollover prior the roadside hazard impact
- Two involved fatal injuries and one involved serious injuries

Note that a stobie pole is a composite utility pole unique to South Australia made of steel and concrete.

The majority of the vehicles were light vehicles, however the sample contained 11 heavy vehicles that were travelling on the through road (unit 1) and four that were required to give way (unit 2).

The speeds of the vehicles at impact are directly related to the crash energy and therefore not only the injury severity but also the post impact trajectory. Impact speeds from reconstructions existed for 43 of the 70 crashes. A matrix showing the combinations of unit 1's and unit 2's impact speeds is displayed in Table 2. The most common impact speed for unit 1 was 80-99 km/h. For unit 2 the most common impact speed was 0-19 km/h. Such low impact speeds for unit 2 most likely represent vehicles that have stopped at the intersection and then proceeded to drive into the path of unit 1. Note that the impact speed of unit 1 may be very close to or much lower than the travel speed, depending on how much braking was applied before impact (if any). The most common combination was unit 1 having an impact speed of 60-79km/h and unit 2 having an impact speed of 0-19km/h, however there was a large range of combinations found. In general, unit 1 had a higher impact speed than unit 2: in only two of the 43 crashes was this not the case.

Table 2: Rural intersection crashes by impact speed and unit

Unit 1 impact	Unit 2 impact speed						
speed	0-19	20-39	40-59	60-79	80-99	100-119	Total
0-19	0	0	0	1	0	0	1
20-39	0	0	0	0	0	0	0
40-59	5	2	1	0	0	0	8
60-79	6	4	1	1	0	1	13
80-99	4	3	5	4	0	0	16
100-119	1	3	1	0	0	0	5
Total	16	12	8	6	0	1	43

The final positions of vehicles involved in a crash at a high speed rural intersection are plotted in Figure 3. Note that in some crashes investigated the final position of one of the units could not be determined, therefore, while there were 70 crashes investigated involving 140 units, only 129 final positions and other associated data are known. The majority of the final positions are clustered within 30 metres of the centre of the intersection, although some go well beyond that range. The vehicles that travel a large distance from the intersection appear to do so at a relatively shallow angle. These cases may represent cases where the mass ratio between unit 1 and unit 2 was particularly high, such as when unit 1 was a large truck and unit 2 a light vehicle.

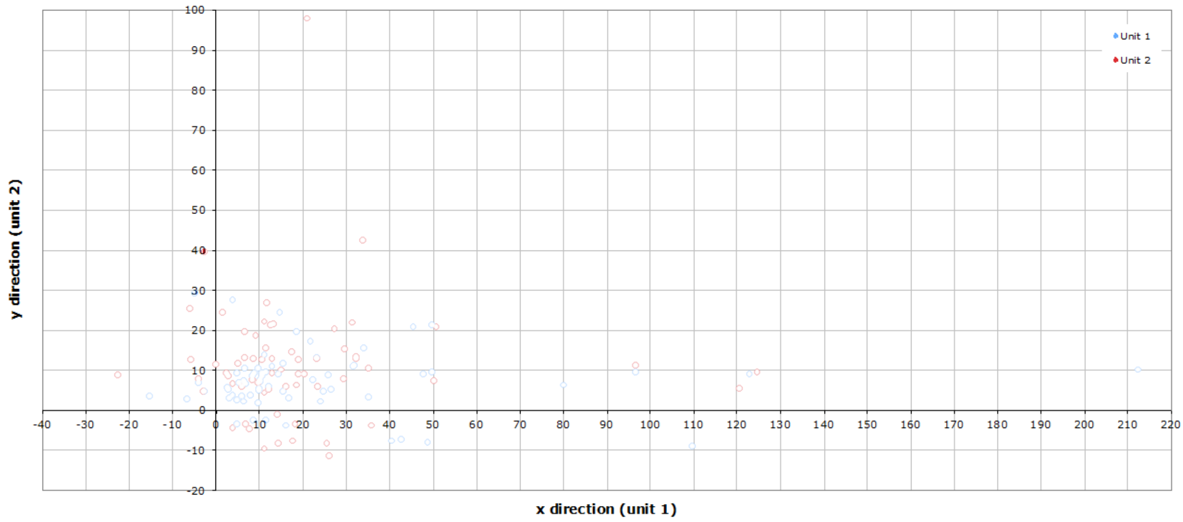

Figure 3: Final positions of crash involved vehicles at rural intersections (n=129)

The cumulative distribution of the straight line distance between the centre point of the intersection and the vehicles final position is shown in Figure 4. Half the vehicles travelled more than 18 metres, 20% more than 34 metres and 10% more than 50 metres from the centre of the intersection, following a collision.

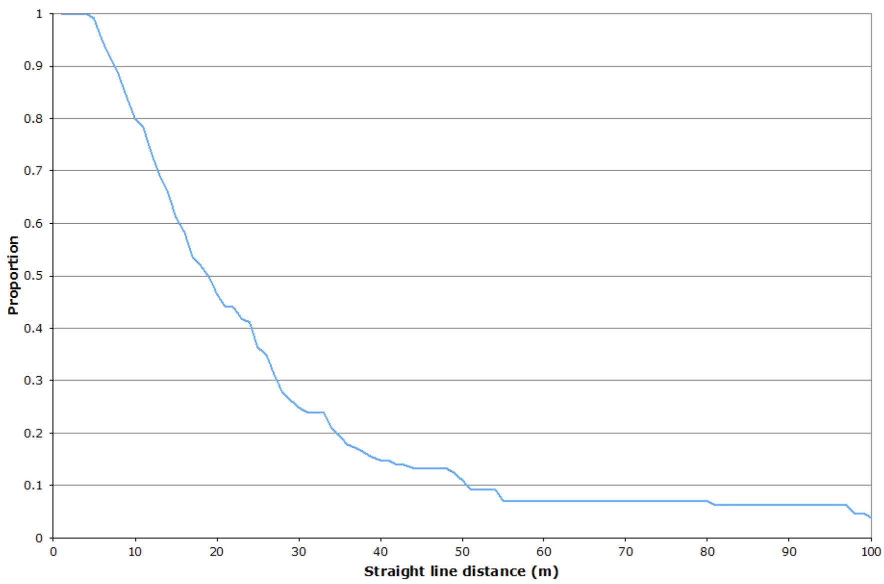

Figure 4: Cumulative distribution of straight line distance of a vehicle following a rural intersection collision

Table 3 displays the straight line distance travelled and angle after impact of the rural intersection crashes; by the speed limit of on the road that had right of way (unit 1's road of travel), the intersection geometry, the impact point on the vehicle and the ratio of unit 1's mass to unit 2's mass. The median and the mean are displayed because the groups contain some outlying values. In general the median provides the more reliable point of comparison. The number of crashes in each individual bin is also shown.

For unit 1 the straight line distance increases as the speed zone increases, while the angle decreases as the speed zone increases. A similar relationship appears to exist for unit 2 although the crashes in 80 or 90 km/h zones do not follow this trend. For both unit 1 and unit

2, collisions that occur at a cross road result in higher straight line distances and higher angles than collisions that occur at a T-junction.

The distance that unit 1 typically travelled from the centre of the intersection increased as the impact moved further from the front of the vehicle, peaking at impacts between the B and C pillars and then reducing again for impacts between the C pillar and the rear of the vehicle. It should be noted that only one impact occurred between the C pillar and the rear of the vehicle in the crashes investigated. The angle for unit 1 is highest for impacts between the front of the vehicle and the A pillar. For unit 2 the distance travelled from the centre of the intersection increases for frontal impacts, peaking at impacts between the A and B pillars, before reducing again as the impact point moves towards the rear of the vehicle. Unit 2's angle is lowest when the impact is located between the front of the vehicle and the A pillar, increasing as the impact moves further towards the rear of the vehicle.

The mass ratio was calculated by dividing the mass of unit 1 by the mass of unit 2. When the mass ratio is above two the straight line distance travelled after impact of both unit 1 and unit 2 is the greatest. This is most likely due to unit 1 being a heavy vehicle and therefore having a relatively large amount of momentum. This is also reflected in the low angles that are observed in collisions between vehicles with a mass ratio greater than two. The angle was highest for unit 1 and unit 2 in crashes with a mass ratio of less than 0.50. This may also be due to a heavy vehicle being involved in the collision, this time as unit 2.

Table 3: Post impact straight line distance and angle of units involved in rural intersection crashes by speed limit for unit 1, intersection geometry, impact point and mass ratio

	Number	Unit 1				Unit 2			
		Distance		Angle		Distance		Angle	
		Median	Mean	Median	Mean	Median	Mean	Median	Mean
Speed limit for unit 1									
50 / 60 /70	7	12.7	13.8	46.3	61.8	18.3	20.6	44.8	47.0
80 /90	15	13.6	28.4	28.2	42.7	15.0	26.7	50.5	51.8
100	28	17.0	20.4	27.1	28.0	21.6	25.0	30.2	32.4
110	20	21.0	41.8	14.9	24.9	23.5	33.6	22.6	29.3
Intersection Geometry									
Cross roads	37	17.8	27.3	38.1	37.5	24.3	28.6	35.1	35.3
T-junction	33	12.5	28.3	24.4	29.1	15.7	26.1	29.3	39.1
Impact Point									
Front	43	12.3	26.8	25.1	30.3	18.6	25.0	49.7	35.4
Front to A pillar	14	15.9	21.2	40.3	51.1	19.4	22.4	18.6	12.6
A to B pillar	8	28.1	42.3	32.8	33.5	24.8	39.7	36.4	40.0
B to C pillar	4	39.3	33.8	7.2	7.6	19.8	19.9	64.8	69.2
C pillar to rear	1	16.0	16.0	16.3	16.3	13.2	13.2	90.2	90.2
Mass ratio									
< 0.50	5	15.7	16.4	61.2	84.9	24.2	23.0	93.9	95.4
0.50 - 0.74	6	20.5	21.6	46.3	54.1	26.4	46.9	28.7	34.0
0.75 - 0.99	14	19.4	22.8	24.4	34.6	22.8	24.1	51.3	44.0
1.00 - 1.24	15	11.2	20.3	26.0	19.3	17.1	16.8	41.1	33.7
1.25 - 1.49	11	11.0	12.1	31.4	45.8	16.6	18.9	35.3	35.2
1.50 - 1.99	7	15.0	16.0	34.6	24.7	18.6	22.4	27.3	36.3
> 2.00	12	50.7	72.6	10.7	12.6	34.5	51.0	14.1	12.9

Figure 5 is a graphical representation of the percentage of vehicles that travel through a given sector surrounding the centre point of the intersection. For the 70 crashes investigated, the figure:

- covers a range of crash configurations and impact speeds
- can be interpreted practically as the chance of a vehicle striking a hazard within a given sector (for example, a hazard located between 10 and 15 metres from the centre point of an intersection, at an angle of between 15 and 30 degrees, has a chance of between 15.1 and 20% of being struck by a vehicle involved in a collision at a rural intersection)
- reveals that the most common post impact trajectory for a vehicle was between 15 and 30 degrees
- shows that more vehicles travelled beyond 40 metres of the centre point of the intersection at a shallow angle of between 0 and 15 degrees
- When the angle was outside the range of 0 to 45 degrees less than 5% of vehicles travel further than 20 metres from the centre point of the intersection in any given sector.

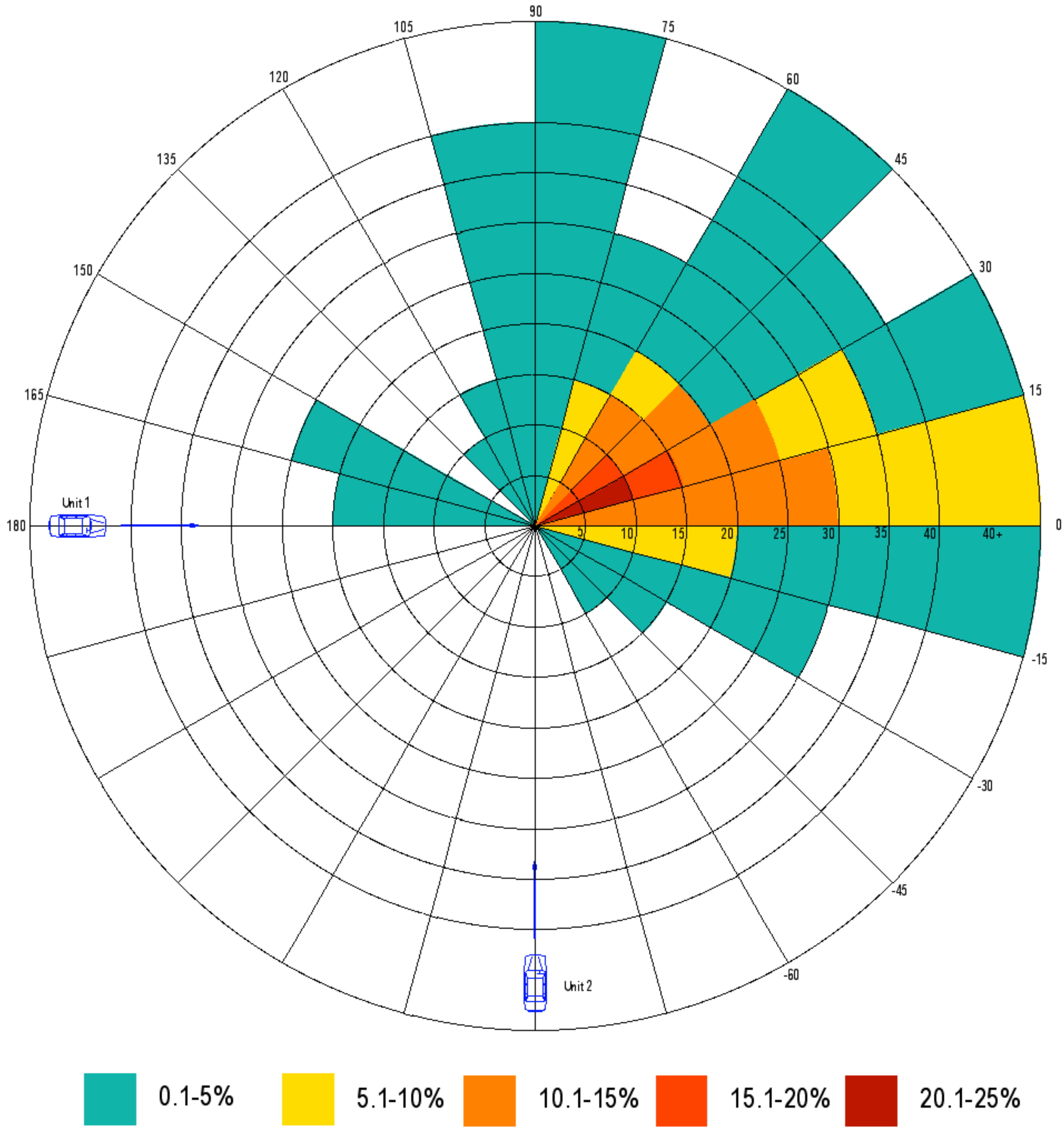

Figure 5: Percentage of vehicles that travel through a given sector surrounding the centre point of a rural intersection

Discussion

A limitation of this study, in particular Figure 5, is that vehicle trajectories have been assumed to be linear from the centre point of the intersection to the final resting position of the vehicle. In real life the path the vehicle travelled may be curved. This mostly affects the sectors close to the centre of the intersection in Figure 5.

The greater straight line distances and angles observed at cross roads, as opposed to T-junctions, may be the result of higher impact speeds of unit 2, whose driver is not aware of either the intersection or their responsibility to give way. Such errors should be less likely at a T-junction where the requirement to give way is more explicitly implied in the road geometry and the presence of an intersection is indicated by the termination of the road unit 2 is travelling on. Cross roads should therefore be afforded more roadside clear of hazards.

It is interesting to note the effect that the impact point has on the post impact trajectory of a vehicle, although this has no direct bearing on the design of the intersection. For unit 1 the worst impact, in terms of post impact trajectory, is an impact between the B and C pillar of the vehicle. Such an impact would be behind the centre of gravity of a typical vehicle and would therefore induce an uncontrolled yaw into unit 1 without slowing it significantly. While such an impact in itself may not be severe the subsequent high speed loss of control may result in a severe impact with a roadside hazard.

Other research has highlighted the benefits of barriers as opposed to clear zones or wide medians on rural high speed roads [4, 5]. Barriers are not typically recommended at intersections because the impact angle may be very high and the least aggressive barrier types, such as wire rope barriers, can not be used due to the small radii often required [2]. Barriers are only recommended at intersections in specific locations, such as on an overpass, where the risk to all road users is particularly high if a vehicle is not contained [2]. The results presented in this paper have shown that a high number of vehicles travel a large distance at a shallow angle following an intersection collision (Figure 5) therefore extending a barrier on the through road (the road with right of way) right up to the intersection may have some benefit.

Clear zones surrounding the intersection would aid in creating a safe system providing they are of adequate size. Removing hazards around an intersection will have the added benefit of increasing sight distance.

It is suggested that future research work could stratify the sample into heavy vehicle types and also consider how motorcycle collision could be included. Rear end collisions could also be investigated to see if final resting positions are significantly different to those of vehicles approaching from different directions.

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