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Impact Of Road Infrastructure And Environment On Powered-Two-Wheelers Injury Severityat Non-Signalized Intersections In A Developing Country – Mauritius

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Abstract
Powered-Two-Wheelers or PTWs (motorcycles and mopeds) play an important role for mobility worldwide. Despite their advantages, including low cost, space and fuel efficiency, the risk of sustaining serious or fatal injuries for PTW riders is higher than for other vehicleoccupants. Education and enforcement measures alone are not enough to fully tackle the road safety problem. On the basis of the Safe System approach to road safety contributory factors related to the road infrastructure and environment also need to be considered. PTWs users are particularly vulnerable at unsignalized road junctions. This study explores the road engineering determinants which influence PTW rider injury severity at four types of unsignalized intersection: roundabouts, crossroads, Y-junctions and T-junctions. Using PTW-involved crash data in Mauritius from 2014 to 2016, the contributory factors of severe injury (fatal or serious injury) were identified using the logit analysis method. A wide range of explanatory variables potentially affecting injury severity was considered, including road characteristics, environmental characteristics and crash characteristics. Our findings show that roundabout junction-type, yield-controlled junctions, road-lighting conditions at night, rear impact, right-angle collision, head-on collision and crashes occurring during weekends to be associated with PTW crashes involving severe injury.

Keywords: Junction-Type, Junction Control, Crash Type, Motorcycle And Mopeds, Crash Severity

INTRODUCTION

The last decade has witnessed sustained growths in the contribution of powered two-wheelers (PTWs; moped and motorcycles) to transport, mobility andthe economy in many parts of the world [1] [2]. In developing countries, specifically in the South-East Asian regionthe share of PTWs are remarkably high consisting of about 75% of the total motorised vehicles [2]. As a mode of transportation, PTWs offer many economic, environmental and social advantages relative to automobiles. PTWs are being preferred for both private and commercial trips as they present numerous uncontested benefits like relatively much lower purchase and running costs, ability to pass through traffic congestions and requiring less lane and parking space [4].

PTWs are also relatively low-emission vehicles and have lower environmental footprint than automobiles [3]. Simultaneously PTWs are quite efficient for overcoming social exclusion as they enable access to work, training or education in areas of the world where public transport is unreliable, automobiles unaffordable, and commuting by bicycle unrealistic or impractical. There is no doubt that the fleet of about 455 million PTWs worldwide will continue to expand and be an essential component of mobility solutions in the future [3]. Despite the prominence of PTWs in many parts of the world these vehicles suffer from a lack of consideration in the transport system whereby most of the world’s existing public roadshave been primarily designed and/or constructed from the perspective of automobile traffic[5][6] [30]. International casualty statistics shows that PTWs riders, to a larger extent in developing countries, are among the road users who are the most vulnerable to road risks in term of crash occurrence and injury severity. In 2016 PTWsaccounted for about 378 000 fatalities representing 28% of all traffic-related deaths world-wide [2].

The road safety problem in Mauritius is quite alarming whereby the number of road traffic crashes have almost doubled over one and a half decade, increasingfrom 19,178 in 2003 to 29,627 in 2018. For the same period the number of injury accidents increased from 2,061 to 3,041[7]. The road crash fatality rate for Mauritiusfluctuates around an average of 12 per 100,000 since the last decade with no sign of a consistent decline [2].

In Mauritius, several legal and infrastructural measures have been put in place in order to prevent road traffic crashes. For controlling speed, since 2013 there are 62 fixed speed cameras installed at strategic points along 1500 km of major roads which are supplemented by hand held speed detectors by the

Traffic Police. Fines for illegal speeding are can be as high as 10,000 MUR (Mauritian rupees). Protective helmet use for both motorcyclists and their pillion riders have been mandatory since decades with controlled importation regulations concerning quality since 1999. For further enhanced quality control of helmets a Mauritian Standard MS 141:2007 was developed based on the British Standard (BS 6658:1985) for motorcycle helmets. Since 2014 wearing of retroreflective jackets during nighttime and use of dipped headlights at all times are compulsory for all PTW users. The legal blood alcohol concentration (BAC) for drivers has been constantly reviewed and reduced over the years from 80 mg/dL of blood to 50 mg/dL and as from 2018 it has been revised to 20 mg/dL of blood. The penalty for driving under the influence of drugs or with a BAC level above the legal limit is an immediate disqualification from holding a driver's license for a period of not less than 12 months and a fine up to 50,000 MUR. In severe cases, imprisonment can go up to 5 years for a first-time offender and up to 8 years for a second-time offender with fines amounting up to 75,000 MUR and the driving license revoked.

Contributing to 38% of motorized vehicle in Mauritius, PTWsare the second most important vehicle category in the country after passenger cars which comprise 42% of the vehicle fleet [8].However, regarding road crash fatalities, PTWs stand first representing 39 % of all road crash deaths and this rate persists since the last six years.In Mauritius, about 22% of all PTW crashes result in serious or fatal injury to the PTW riders [2][8]. Almost 35% of PTW crashes occur at intersections in Mauritius whereby 30% occur at unsignalized junctions which are roundabouts, crossroads, T-junctions and Y-junctions. Other studies have also highlighted that the probability that a severe/fatal accident occurs at intersections is higher than at non intersection locations [11]. Thus, analysis of PTW crashes at unsignalized junctions in Mauritius would contribute to get better understanding of these motorized two-wheeler crashes at intersections in order to counteract the road safety problem in developing countries.

Road safety researches have established that a road crash is a complex multi-factor event involving the interaction of human, vehicular, road infrastructure and road environment factors [10]. The majority of theexisting literatures on PTW road traffic crashes at intersections have highlighted mostly on the human behavioral and socio-economic determinants of crash occurrences [9] [13].The most common of PTW crash type at junctions has been found tobe the right of way violation, whereby a vehicle pulls out froma lateral road onto a main carriageway into the path of an exiting or converging PTW[15] [17].Some studies have shown that risk taking, impulsive sensation seeking, aggressionof PTW users at signalized intersection were highly responsible for severe PTW crashes [25] [26] [27].Regarding crashes involving human errors, studies havededuced that PTWs get involved in accidents because of the fact that automobile drivers did not detect the PTW or because the other vehicle driver detected the motorcyclist but failed to judge correctly the speed/distance of the oncoming PTW [14] [24]. Referring to studies concerning PTW crashes at intersection, it has been highlighted that the complexity of conflicting movements and manoeuvres between motorcycles and automobiles increase PTW injury severities at junctions [19] [20]. Also, it has been underlined that junction-type crashes can be more severe to motorcyclists than a non-junction crash because of the occurence of angle collision at such locations [16] [18].

Despite the fact that human failings are important contributory factors to PTW road crashes resulting in fatalities and severe injuries, yetroad infrastructure and environment related factors of such crashes have not been sufficiently explored. It is crucial to identify road engineering contributory factors which act complementarily with human and/or vehicle factors to cause high severity injury crashes in order to develop efficient countermeasure for addressing the road safety problem. With regard to the Safe System approach it is understood that education and enforcement cannot be the only measures taken to reach efficient road safety, the consideration of relevant infrastructural and road environment related measures are crucial [28].

Powered-two-wheeler riders are highly over-represented in road traffic crashes causing severe injuries in Mauritius and many other developing countries [2] and a high proportion of these crashes occur at unsignalized junctions. The interaction of road infrastructural and environmental determinants of PTW crash severity at unsignalized junctions has not been explored.

The purpose and objective of this study is to determine the relevant factors resulting from the interaction of road infrastructure and environmental characteristics contributing to fatal and serious PTW crashes at unsignalized junctions in a developing country context. The identification of the afore-mentioned factors would be relevant to road authorities for the developments of evidence-based countermeasures for the improvement of road safety for PTW riders in Mauritius and other countries with similar traffic mix and road conditions. The findings would also provide more insights for improvements in unsignalized junction design.

MATERIALS AND METHODS

Data Source

The data used in this research was retrieved from the road accident database of the Ministry of Public Infrastructure of Mauritius; Traffic Management and Road Safety Unit (TMRSU). The source of the data is the Traffic Branch of the Mauritius Police Force. All data concerning injury traffic accident for the whole island is recorded by the police on a form known as the Police Form 178 (PF 178) which caters for the recording of about 100 details for every accident. This form is inclusive of an accident data management system supported by the Micro Computer Accident Analysis Package 5 (MAAP 5) software which was developed for Mauritius by the Traffic Research Laboratory (TRL) of the United Kingdom (UK) in the year 2002.

For every injury accident, police officers have the obligation of drawing up a PF 178 form with maximum of details available at the accident spot followed by a monitoring with surviving accident victims, eyewitnesses and hospitals to be able to complete the form with a maximum of required details. The responsibility for computerization and processing of all recorded details from the PF 178 form onto a MAAP database is dual. It is done on one hand by officers of the Central Statistics Office (CSO) for national statistical records and on the other hand by police officers of the Traffic Branch police department thus allowing comparison for data input errors. The TMRSU is liable for handling the centralized injury accident MAAP database from the police department for scientific and technical exploitation. It is from the latter database that PTW injury accidents for the whole country and for the years 2014, 2015 and 2016 has been retrieved for this study.

Currently, the level of under-reporting for injury road accident in Mauritius is estimated to be very low. The police are always notified in the event of an injury accident whether it is slight, serious or fatal injury type. This is because even slight injury accidents also involve some damage to the PTWs involved whereby reporting to the police is necessary for insurance claim procedures. For serious and fatal injury types the police department is definitely involved. The definitions of injury severities for all road traffic accidents have been revised to match up and be more consistent with international descriptions.

DEFINITION OF VARIABLES

The Response Variable

The response variable for this study is the ‘injury severity’ of PTW injury accidents in Mauritius for the years 2014, 2015 and 2016.An injury accident is one whereby at least one person has been either killed or injured as a result of the traffic accident. The database provides three categories of injury severities namely, fatal, serious injury and slight injury.In Mauritius a fatal injury accident is defined as an accident where deaths occurred within 30 days of sustaining injury. A serious injury accident is one whereby an injured person is admitted to a hospital as an "inpatient" for more than 24 hours whereas for a slight injury accident a person receives medical care but is not admitted to hospital for more than 24 hours.The three aforementioned injury severity categories were redefined into two categoriesby merging the fatal and serious injury cases into a single category and named ‘severe injury’ and the second category was the ‘slight injury’ cases. Thus with two possible outcomes ‘injury severity’ was a dichotomous dependent variable.

The ExplanatoryVariables

The Road Factors comprised severalvariables, namely; ‘Road Alignment’, ‘Road hierarchy’, ‘Junction Type’ and ‘Junction Control’. The Environment Factors consisted of two temporal factors, ‘Crash Time’ and ‘Crash Day’. Other Environment Factors included were ‘Light condition’ and ‘Weather Condition’. The Crash Characteristics variables considered were‘Collision Type’, ‘PTW Manoeuvre’, ‘Collision Partner’, ‘PTW Type’ (moped or motorcycle) and ‘Pillion Rider’ which denotes the presence or absence of a passenger on the PTW at the moment of the crash. The different categories for each of the afore-mentioned explanatory variables are shown in Table 1.

Statistical Analysis

A descriptive statistical analysis was performed for all the categories of the dependent and independent variables; the results are tabulated in Table 1 below.
Logit analysis was used for determining association of relevant predictors with severe PTW crashes at non-signalized intersection. Prior to the analysis, the VIF (variance inflation factor) was determined to assure that there were no excessive multicollinearity among explanatory variables. The logit analysistechnique has been used in many fields of research topredict a dependent variable on the basis of categorical predictors. All the explanatory variables in this analysis were categorical variables. Logit analysis enable the determination of the effect size of the predictor variables on the dependentvariable, the ranking of the relative importance of predictors and thus provide an understanding of the level of impact ofcovariate control variables.

Logit analysis predicts the log odds of thedependent event. The “event” is a particularvalue ofthe dependent variable. In binary logit analysis, the outcome of interest in the dichotomous dependent variable is coded‘1’and thereference category is coded'0'. In this analysis the 'severe injury' (fatal or serious injury) outcome was coded '1' and 'slight injury' outcome was coded '0' The logit analysis equation is expressed as:

$$g(x) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_n X_n$$

where,
$g(x)$ = the log odds of the dependent variable.Individual predictors in the analysis were tested
using Wald's test while the goodness of fit of the model was assessed using Hosmer-Lemeshow test which follows a chi-square distribution. Large p-value for the Hosmer-Lemeshowtest indicates model significance which means the logit analysis has efficiently identified association of significant predictors with the independent variable [21].

In this analysis the multivariate stepwise logistic regression analysis was used to identify significant factors determining severe PTW accidents at unsignalized junctions in Mauritius and to estimate the magnitude of adjusted odds ratios (ORs) for eachsignificant factor while controlling for other confounding factors [22]. The adjusted ORs of significant factorsand their 95% confidence intervals (CIs) are computed using astepwise logistic regression model in which all factors were initiallyincluded and from which insignificant factors were subsequentlyremoved by the stepwise procedure. Entry and removal probabilities for the stepwise procedure were both set at 0.05. The statistical software used for the analysis was IBM SPSS version 25.

RESULTS

Descriptive statistics

Of the 1438 PTW crashes 318 (22.1%) were severe injury (fatal or serious injury) crashes and 1,120 (77.9%) were slight injury crashes. Table 1 shows the distribution of the severity of PTW crashes across a variety of factors, including road, environment and crash characteristics including the type of PTW (moped and motorcycle).

Concerning the road factors, when considered separately without the effect of other factors, T-junctions (50.9%) and crossroads (36.2%) were found to be the most hazardous junction types regarding crash severity. With regard to the road alignment at intersections the majority of severe crashes ware found to occur on roads with straight and level configuration as compared with junctions located at curved alignments. The junction control type which caused more severe PTW crashes were found to be STOP controlled junctions (77%). Two-way road (87.1%) were found to be much more dangerous for PTW severe crashes compared to one-way roads and dual carriageways.
Considering the environmental factors, the majority of severe PTW crashes occurred on clear weather (94.0%) conditions during the day under daylight conditions (60.1%). Also, a higher proportion of severe crashes happen on weekdays (64.8%) during evening peak hours, 15.00 – 19.59 (35.5%).

The descriptive statistics of the crash characteristics show that PTW collision with passenger cars is the most hazardous causing severe injury to the PTW user (42.1%). Loss of control causing the PTW to run off-road was found to be also quite detrimental to PTW riders causing 18.2% of severe injuries regarding collision partner**[12]**. With regard to the PTW manoeuvre it was found that more severe crashes occurred (67.9%) when the PTWs were undertaking a forward movement. The type of impact causing more severe injury to the PTW rider was revealed to be head on crashes (45.6%). PTW users riding alone (80.5%) were found to be more prone to severe crashes relative to those carrying a passenger. Motorcycles with 76.7 % of severe injury crashes were found to be more hazardous than mopeds.

Table 1 Descriptive statistics of PTW Severe and Slight injury crashes occurring at non-signalized intersections in Mauritius, 2014-2016

	Severe injury		**Slight injury**	
	n	**%**	**n**	**%**
Powered-two-wheelers (PTWs) injury crashes (N= 1438)	318	22.1	1120	77.8
ROAD FACTORS				
Junction type				
Round-about	34	10.7	189	16.9
T-junction	162	50.9	550	49.1
Crossroad	115	36.2	354	31.6
Y-junction	7	2.2	27	2.4
Road Alignment				
Straight with longitudinal grade	3	0.9	17	1.5
Curve with longitudinal grade	6	1.9	32	2.9
Horizontal curve	18	5.7	96	8.6
Straight and level	291	91.5	974	87.0
Traffic Control				
Uncontrolled	30	9.4	136	12.1
Yield sign	43	13.5	187	16.7
STOP sign	245	77.0	797	71.2
Road Hierarchy				
Dual carriageway	13	4.1	74	6.6

One-way road	28	8.8	122	10.9
Two-way road	277	87.1	924	82.5
ENVIRONMENTAL FACTORS				
Weather condition				
Clear	299	94.0	1039	92.8
Rainy/fog	19	6.0	81	7.2
Light condition				
Dark (no lighting/unlit)	14	4.4	35	3.1
Dawn/Dusk	24	7.5	112	10.0
Daylight	191	60.1	791	70.6
Road lighting	89	28.0	182	16.3
ENVIRONMENTAL FACTORS (TEMPORAL)				
Crash Day				
Weekends	112	35.2	314	28.0
Weekdays	206	64.8	806	72.0
Crash Time				
10:00 - 14:59	76	23.9	314	28.0
00:00 - 04.59	19	6.0	24	2.1
05:00 - 09:59	64	20.1	273	24.4
15:00 - 19:59	113	35.5	401	35.8
20:00 - 23:59	46	14.5	108	9.6
CRASH CHARACTERISTICS				
Collision Partner				
Pedestrian or animal	25	7.9	96	8.6
Heavy goods vehicle/Bus	51	16.0	192	17.1
Powered-two-wheeler (PTW)	18	5.7	67	6.0
Light goods vehicle (van)	32	10.1	95	8.5
Ran off-road/hit object	58	18.2	251	22.4
Passenger car	134	42.1	419	37.4
PTW Maneuver				
Merging/Diverging (same side)	35	11.0	105	9.4
Forward	216	67.9	772	68.9
Right-turn	18	5.7	97	8.7
Overtaking	49	15.4	146	13.0
Crash Type				
Side Swipe	37	11.6	151	13.5
Hit Pedestrian/Animal	12	3.8	73	6.5
Rear Impact	41	12.9	113	10.1
Right-angle Impact	26	8.2	87	7.8
Ran off-road/Hit object	57	17.9	249	22.2
Head On	145	45.6	447	39.9
Pillion Rider				
No pillion rider	256	80.5	933	83.3
Pillion rider	62	19.5	187	16.7
PTW type				
Moped	74	23.3	300	26.8
Motorcycle	244	76.7	820	73.2

Logit Analysis

The final output of the stepwise logit analysis removed the independent variables which did not have any association with the severity of PTW crashes at un-signalized intersections. Thus for this analysis, it was deduced that for the road-related variables 'Road Hierarchy' and 'Road Alignment' did not have any association with severity of PTW crashes at non-signalized junction. For environment-related variables 'Crash Time' and 'Weather Condition' did not affect severity of crashes. Regarding the characteristics of crashes ('Crash Characteristics'), it was found that 'PTW type', the presence or absence of a 'Pillion Rider', the 'collision partner', and the 'PTW Manoeuvre' were irrelevant variables with regard to influencing severity of PTW collisions in this analysis.

Regarding non-signalized intersections in Mauritius, the result of the logit analysis deducted that 'Light Condition', 'Junction Control', 'Junction type', 'Collision Type' and 'Crash Day' were significant factors which associated with severe PTW crashes at non-signalized junctions in Mauritius. The details of the relevant categories are tabulated in Table 2.

The 'Light Condition' variable had a significant overall effect (*Wald=21.54.00, df=3, p=<.0005)* on PTW severe injury crashes relative at non-signalized junctions to slight injury crashes. Relative to daylight, the odds of severe (fatal and serious) injury crashes relative to slight injury crashesincreasedby 99%for crossroads, T-junctions and roundabouts illuminated by road lighting at night. The 'Junction Control' variable (*Wald=14.29, df=2, p=.001)* was highly significant for severe injury crashes. Relative to uncontrolled junctions, the odds of severe injury crashes increased by 13.80 times for yield controlled road intersections as compared to slight injury crashes. 'Junction Type' was also found to be highly significant (*Wald=17.67, df=3, p=.001)*.Relative to Y-junctions, the odds of severe PTW crashesat roundabouts were 95% lower than slight injury crashes.

Table 2 Risk factors associated with severe (fatal or serious) injury crashes for PTWs at non-signalized intersections in Mauritius, 2014 - 2016

				95% of CI	
	B	p	Odds Ratio	Lower	Upper
Crash day					
Weekday*					
Weekend	0.298	0.033	1.347	1.024	1.771
Light condition					
Daylight*					
Dawn/dusk	-0.057	0.812	0.944	0.588	1.516
Dark (no lighting/unlit)	0.555	0.097	1.742	0.904	3.357
Road lighting	0.688	< 0.0001	1.99	1.462	2.708
Junction control					
No control*					
STOP control	0.27	0.276	1.31	0.806	2.129
Yield control(Give way)	2.694	< 0.0001	14.797	3.658	59.849
Junction type					
Y-junction*					
T-junction	-0.223	0.646	0.8	0.31	2.07
Crossroad	-0.186	0.71	0.831	0.312	2.213
Round-about	-3.111	< 0.0001	0.045	0.008	0.236
Collision type					
hit pedestrian/animal*					
side swipe	0.587	0.119	1.799	0.861	3.76
right-angle collision	0.788	0.049	2.199	1.005	4.81
rear impact	0.837	0.026	2.308	1.105	4.824
ran off-road/ hit object	0.473	0.188	1.605	0.794	3.244
head on	0.797	0.019	2.22	1.139	4.325

*indicates the reference group

The temporal variable 'Crash Day' was also significant whereby the odds of severe PTW crashes were 34.7% higher on weekends relative to weekdays. From the different categories of the 'Collision Type' variable it was found that in comparison to crashes against pedestrians or animals, the odds of severe injury increases by 130.8% for rear impact crashes, by 122.0% for head-on crashes and by 119.9% for right-angle crashes regarding PTWs crashes with other vehicles at non-signalized junctions.

DISCUSSION OF RESULTS

Using logit analysis, the current research has highlighted the determinants for severity of PTW crashes at non-signalized junctions, namely; roundabouts, crossroads, Y-junctions and T-junctions.Y-junctions or three-legged junctions were found to be the most hazardous junction types and roundabouts more dangerous for PTWs crash severity than T-junctions and crossroads.This can be explained by the geometrical layout of Y-junctions which may consist of skews with acute angles which simultaneously decrease visibility and make PTW manoeuvre more difficult. At exit or entry points, roundabouts are identical to a three-legged junction or Y-junction whereby two legs join to form a curved segment. According to [23] high severity crashes should be effectively eliminated at well-designed roundabouts due to reduced speeds on approach and through the roundabout, throughreduction in angle of impact, and through the reduction of conflict points. However, poor design (including poor visibility on the approach, high entry speeds, or poor deflection through the roundabout), can lead to severe crashes [23].The geometrical characteristics of roundabouts permits better visibility than Y-junctions during the day and also on roundabouts the conflicting traffic are from one direction only as compared to Y-junction involving exit on a two-way road.Multiple lane, higher volume roundabouts can be confusing, and may not have adequate influence on vehicle path deflection and therefore speed. The hazardousness of roundabouts for PTWs may also be due to the relatively extremely low radius curve at exit/entry points just before/after the roundabout which can be very hazardous if speed is not sufficiently reduced. Crossroads and T-junctions do not have the afore-mentioned difficulties as compared to Y-junctions and roundabouts.

Adding to the constraint existing due to the geometrical layout, the type of junction control at non-signalized intersections highly influence the safety of PTW. The outcome of this research show that yield controlled (Give Way) junctions further magnify the afore-mentioned geometrical constraints for PTWs. For yield controlled intersections both the approach and departure sight distances are crucial with regard to road safety. The minimum requirement for the approach sight line distance is for drivers on both roadways approaching an intersection to have the ability to recognize a potential conflict on the intersecting road and make a decision to accelerate, decelerate or stop in sufficient time to avoid a collision. Regarding the determination or verification of the approach sight line distance for the vehicle approaching the yield condition, the calculation of decision sight distance should be preferred to stopping sight distance as decision sight distance is much greater than stopping sight distance for a given design speed. The high severity of motorcycle crashes at yield type junction can be mainly attributed to insufficient sight distances due to built-up areas and/or vegetation obstructing sight lines at these junctions and the speed of vehicles approaching these junctions.

Further adding up and magnifying the constraint and increasing the hazardousness of PTWs at non-signalized intersections is the lighting problem at night. Reduced conspicuity under road lighting at night continue to be a major problem for PTW users even after implementation of compulsory wearing of retroreflective jackets during night-time and use of dipped headlights at all times. In Mauritius the afore-mentioned policies have been implemented since the year 2014 in order to counteract the lack of conspicuity issue regarding PTW users which do not seem to be sufficient. Inadequate road lighting at night also compromise the visibility and readability of road signage which are crucial for road safety. Road lighting design should consider relevant parameters such as traffic volume, road cross-section, intersection conditions, road geometric properties including horizontal and vertical alignments, nature and surface texture of pavement with regard to light reflection, spacing of light poles and accident rate in order to deduce the optimum lighting requirements for efficient illumination with regard to road safety [29]. The re-design of existing road lighting with due consideration of significant design parameters or changes in the parameters can optimize the amount of road illumination at night and thus increase road safety for PTW users.

The category for the ‘crash day’ factor with statistical significancewas ‘weekend’. The increased likelihood of severe PTW crashes during weekends can be explained by the fact thatweekend riding is generally for recreational purposes rather than commuting purposes [31].Use of PTWs for recreational purpose increase the possibility of night riding and as mentioned in the previous paragraph, riding under road lighting increase the likelihood of severe injury crashes for PTW users.

Finally, collision type was found to be associated with increased likelihood of severe PTW crashes at non-signalized intersection. The most hazardous type of crash was found to be rear crash. Thefinding seems to be reasonable with regard to the decreased conspicuity of PTWs from behind at night under road lighting illumination. Also, the speed of other vehicles approaching junctions may be too high, mostly during free flow conditions, whereby high speed impact with yielding PTWs in the forefront becomes inevitable. Another possibility may be the increased exposure of yielding or stopped PTWs to rear collisions with yielding vehicles with higher acceleration capacities. The next two dangerous crash types with regard to severity of PTW crashes at non-signalized junctions are head-on and right-angle crashes. Both type of crashes can be attributed to exiting PTWs undertaking a right-turn movement at yield controlled or STOP controlled Y-junctions or T-junctions or crossroads whereby either type of crash can occur depending on the stage of exiting of the PTW. Mauritius being a left-hand side driving country an exiting vehicle at a junction undertaking a right-turn movement may collide with oncoming vehicles under Right-of-Way violation or ‘Looked-But-Failed-To-See’ error situations.

RECOMMENDATIONS AND CONCLUSIONS

The riders’ ability to see the road ahead and other junction users is critical to safe and efficient use of unsignalized intersections. Stopping sight distance, decision sight distance, and intersection sight distance are particularly important at such intersections. It is imperative that drivers be given sufficient distance to perceive, recognize, and react to the presence of traffic control elements such as pavement markings and signage, in addition to the possibility of queued vehicles and the need to maneuver into auxiliary lanes prior to the intersection.

Intersection sight distance is traditionally measured through the determination of a sight triangle. The area of unobstructed sight distance is called the sight triangle. There are two sight triangles that come into play at an intersection, approach sight triangle and departure sight triangle This triangle is bound by a length of roadway defining a limit away from the intersection on each of the two conflicting approaches and by a line connecting those two limits. For a yield controlled intersections, the minimum requirement for the approach sight line distance is for drivers on both roadways approaching an intersection to have the ability to recognize a potential conflict on the intersecting road and make a decision to accelerate, decelerate or stop in sufficient time to avoid a collision. For this reason, the use of decision sight distance should be priotized to stopping sight distance as decision sight distance is much greater than stopping sight distance for a given design speed [32].

Both the approach and departure sight distances must be verified. The approach sight line distance is only required for the vehicle approaching the yield condition and typically a speed less than the posted speed is used. Sight lines depend on two elements; the eye height of the driver and the object height. A constant of 1.05m is normally used which represents the driver's eye when seated in the driver's seat of passenger carsbut for PTWs it should be slightly higher by around 10 -15 cm.

Other geometrical improvements at unsignalized intersections which can improve PTW road safety include realignment of the intersection approaches to reduce or eliminate intersection skew. The latter modification would help solve the problems of insufficient intersection sight distance and awkward sight lines at a skewed intersection. The improvement of the visibility of unsignalized intersections by providing enhanced signage and delineation can be efficient solutions. Unsignalized intersections that are not clearly visible to approaching motorists, particularly approaching motorists on the major road. The strategy is particularly appropriate for intersections with patterns of rear-end, right-angle, or turning crashes (head-on) related to lack of driver awareness of the presence of the intersection. Measures can include installing larger or supplementary regulatory and warning signs at intersections or providing dashed markings (extended left edge-lines) for major-road continuity across the median opening at divided road intersection.

The conversion of yield-controlled junctions into all-way stop-controlled or signalized junctions, depending on the volume of traffic, can maximize junction safety. The improvement of road curvatures at entry and exit points of intersections can also be quite beneficial for PTW users regarding road safety. Choosing the correct traffic control strategy for an intersection is critical to its successful operational and safety performance. Such strategies should be normally selected based on specific warrants which is an essential step in the planning and design process. Improper traffic control types at intersections can result in driver frustration, poor operational performance, reduced driver compliance and thus lead to degraded safety performance.

Unsignalized intersections that are experiencing right-angle, rear- end, and turning crashes can be converted into roundabouts for better safety [33]. The three basic principles of modern roundabouts – yield at entry, traffic deflection, and curvature of the travel path – all work in conjunction to reduce travel speeds, while the circulation of vehicles eliminates many conflict points and also tend to decrease the kinetic energy transfer in collisions. They accomplish this by both slowing down vehicle speeds. Roundabouts can be very effective at intersections with complex geometry (e.g., more than four approach roads) and intersections with frequent left-turn movements[34, 35]. However, proper channelization, optimum entry and departure curvatures adapted to PTW speeds need to be provided.

Improvement of visibility and conspicuity at unsignalized intersection for nighttime traffic through proper verification, re-design and upgrading of existing lighting condition is crucial for counteracting PTW rear-end and right-angle crashes. At night the entire roundabout and especially the central island should be well-illuminated or clearly visible with the headlights of the vehicle. Ground-level lighting of the central island, reflective pavement markings and reflective paint on curbs may increase the visibility. Landscaping the central island increases the conspicuity by reducing the sight distance and making the intersection a focal point.Concerning environmental improvement which would greatly enhance nighttime safety of PTW users at non-signalized junctions is the review and upgrading of road lighting taking into consideration relevant design parameters.

Existing researches on PTW road crash risks at non-signalized junctions have addressed mostly human characteristics and some environmental aspects of crash causation [9,13,14,15,17,19,20,24,25,26,27]. This paper adds to PTW safety research by revealing some road engineering contributory factors that increase the severity of injury (fatal and serious injuries) at non-signalized intersections which had not been included in earlier studies.For improvement of PTW riders' safety at unsignalized junctions, this research highlights the need for infrastructural improvements and safety treatments such as correction of geometrical aspects with regard to improvement of visibility, enhancement of signposting of hazardous junctions and improvement of road lighting. The type of junction control was also found to be a highly relevant aspect with regard to PTW severe injury crashes thereby the review of intersection control type with respect to changes in traffic volume and traffic mix should also be considered.

The identification of significant risk factors increasing severity of PTW crashes occurring from the interaction of the road and its surroundings with environmental elements can be used for the development of targeted corrective and preventive measures at non-signalized intersections in the existing road network and associated works through engineering techniques. The findings can also be considered for improving road safety elements in the design of non-signalized junctions for new road projects.

LIMITATIONS OF THIS STUDY

The data used in this study is frompolice-reportedcrash data which is the primary source of crash variables in Mauritius. There are some data which were not available in the police database and were not included in the study. Unavailable variables which would be relevant for the present research were; speed of vehicles involved in crashes which may from now on be retrieved from recently installed safety cameras at many junctions. Details about the quality of the road surface in terms of road defects, evenness and frictional properties have also not been included. Nevertheless, the findings of this research are very important and useful. The possibility of including other road-related and/or environmental explanatory variable in the study leave ground for future research.

The identification of significant risk factors for severe PTW crashes occurring from the interaction of the road and its surroundings with environmental elements can be used for the development of targeted corrective and preventive measures on problems identified in the existing road network and associated works through engineering techniques.

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