Road Engineering Determinants of Moped and Motorcycle Crashes at Non-Intersection Road Segments in a Developing Country – Mauritius

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Abstract - *The road safety situation is extremely alarming in developing countries where 93% of the worldwide 1.35 millions road crash fatalities occur annually. As in most Low and Medium Income Countries (LMICs), in Mauritius also, powered-two-wheeler (PTW) riders are the most vulnerable road-user category with respect to road crash fatalities and serious injuries. Despite the application of enforcement and education counter-measures for decades the afore-mentioned situation does not ameliorate. With reference to the Safe System approach there is a need for a more holistic approach to road safety whereby the road and the road environment factors of PTW crash risks need to be considered in parallel with road-user and vehicle factors. This research aimed at amplifying awareness about the road engineering factors of PTW crash severity in a developing country context. With this focus the objective of this study was to identify the road engineering determinants of mopeds and motorcycles crash severity at non-intersection road segments in Mauritius. Police-reported data for 3,103 PTW injury crashes over the 3-year period 2014 -2016 was used for the analysis. The Logistic Regression method was used with a dichotomous dependent variable; 'crash severity' and 10 explanatory variables. Specific categories of the 'Road Hierarchy', 'Pillion Rider' and 'Crash Partner' factors were found to be relevant to occurrence of fatal and serious injury crashes for motorcycle at road mid-block. For mopeds, horizontal curves from the 'Road Alignment' factor was found to be the most hazardous road configuration. Three common factors for both PTW types were identified; 'Light Condition', 'Crash Time' and 'Crash Type' but with partly distinct categories. The variables 'Crash Day', 'Weather Condition' and 'PTW Manoeuvre' were not related to crash severity of neither PTW type. The findings of this study can be used by road authorities to improve road safety along non-intersection road segments in developing countries, particularly for PTW riders.*

Keywords: Road engineering determinants, Moped crash severity, Motorcycle, developing country, Safe System.

1. Introduction

Accounting for 1.35 million fatalities and about 50 million injuries annually, road traffic crashes persist as a major cause of premature mortality and disabilities worldwide [1]. The situation is extremely alarming in developing countries where 93% of these fatalities occur; 13% are in low-income countries which have only 1% of the world's registered motor vehicles and 80% in middle-income countries which own 59% of the world's registered vehicles [1]. Apart from the enormous human toll, road safety has a major economic impact with annual crash-related costs estimated to be in the range 2% - 5% of national GDP for many developing countries [2]. The socio-economic impact of road traffic deaths and injuries is greater on

low and middle-income countries (LMICs). According to the World Bank road deaths and injuries hold back economic growth in developing countries. A recent World Bank study showed that sharply reducing the number of road traffic injuries over time would enable developing countries to achieve substantial GDP growth and welfare gains. Curbing road traffic injuries would be a significant milestone for global development, with immediate and far-reaching benefits for public health, wellbeing, and economic growth to reduce poverty and increase shared prosperity [2].

Globally, nearly a quarter of all road traffic deaths occurred among powered-two-wheeler (mopeds and motorcycles) riders with a large proportion occurring in LMICs [1]. After controlling for per vehicle mile traveled, motorcyclists were reported to suffer a 26-fold higher risk of death in a crash than automobile drivers [3]. With an increasing use of powered-two-wheelers (PTWs) in developing countries, due to their economic affordability, the latter are facing a major and growing road safety challenge regarding PTW riders' injury. As a matter of fact, the proportion of PTW related fatalities in some developing countries (2016 figures) were as follows; 74 % in Thailand and Indonesia, 73 % in Cambodia, 65% in Myanmar, 63% in Malaysia and 52 % in Sri Lanka in the Asian region. In the Americas and the Caribbean region; 67% in the Dominican Republic, 53% in Colombia, 52% in Paraguay and 40% in Costa Rica. In some African countries; 72% in Togo, 57% in Benin, 46% in Mauritius and 42 % in Mali [1,4]. The growth in the use of mopeds and motorcycles in developing countries and the over-involvement of this category of road user in severe injury crashes demonstrate the need for a better understanding of PTWs crashes in developing country contexts.

Overall research about PTW road safety have mostly been done in developed nations [8–36] whereby the road infrastructural aspects, the traffic mix and PTW; usage, styles and trip purpose are quite different from the developing world. PTWs with larger engine capacities are mounted for occasional touring and leisure purposes in Australia, US, Canada, and Europe [5]. In LMICs, PTWs with relatively lower engine capacities provide a convenient, affordable and essential mobility solution for daily commuting purposes. Thus the road and road environment related risk factors regarding PTW injuries in developing countries can be different from those in developed countries and more studies coming from developing country are required.

The vast majority of PTW road safety studies have focused on the human factors of crash occurrence and severity in contrast with road and vehicle factors [6]. The road-user factors have been classified into demographics, errors and violations. Some human factors identified in previous PTW safety research are: looked-but-failed-to-see [7], age [8-13], riding without helmets [12-15], alcohol use [12, 13, 15-17] and speeding [12, 15, 18, 19]. Learning from developed nations most LMICs have developed education and enforcement measures to control the road-user factors of PTW crash risks and are still relying mostly on these two traditional counter-measure categories. Understanding the need for a more holistic approach to Road Safety in line with the Safe System approach [20], developed countries are catching up, through research, with counter-measure development relative to road engineering aspects of road crash risks in order to complement education and enforcement countermeasures [21]. Looking at the persistent and alarming nature of road traffic injuries in many developing countries [1], it is evident that the latter are missing out on road and road environment aspects of road crash risk mitigation possibilities. It is crucial to create and amplify awareness about the untapped potential of the road itself as crash risks counter-measure formulation in developing countries.

Some literature specific to road engineering aspects of PTW crash risks safety from countries like Australia, United States and some European countries illustrates the road and road environment factors which were used and were relevant in those studies. The road geometric design factors such as horizontal and vertical curvature have been highlighted to be potential crash risk factors regarding PTW safety [16, 17, 22, 23]. Specific roadway design elements such as number of lanes, lane width and shoulder width have been shown to impact motorcycle crashes [14, 15]. The road surface conditions (loose materials, irregularities, potholes, and wetness) have contributed to the occurrence of sideswipe and loss of control motorcycle crashes [24]. The severity of loss-of-control type of accidents are aggravated when collision with road-side objects were involved [25, 26]. Reduced visibility and conspicuity under different lighting situations was found to increase the severity of

motorcycle crashes [27, 28, 29]. The weather conditions were relevant for influencing motorcycle accident occurrences and severity [30,31]. Studies considering the above-mentioned road engineering factors as input variables for PTW crash risk studies in developing nations would surely contribute in reducing the road safety knowledge gap regarding these countries.

Regarding PTW types, the two main categories which are mostly used in developing countries are mopeds, which are of low engine capacity (≤50cc) and with low speeding possibilities (≤50 km/h), and motorcycles with relatively higher engine capacities (≥ 125cc) and accelerating possibilities. The vast majority of existing studies on PTW road safety have either not considered mopeds or have not differentiated between mopeds and motorcycles. However, it has been highlighted in a few studies that even with speed restraints mopeds can be more hazardous than motorcycles with regard to road traffic injuries [32-36]. Thus, the belief that mopeds are safer PTW types as they cannot attain high speeds can be misleading. To the best of the authors' knowledge, literature about road engineering determinants of mopeds crash risk and severity in developing countries were not available. Thus differentiating between moped and motorcycle in road safety research may enable higher efficiency through specific crash factor identification relative to the PTW types.

Mauritius as the location for this study included an important advantage relative to most of the other developing countries. The country being an island state, provided a semi-bounded system for this PTW road safety study thereby eliminating sampling bias as the whole population of PTW injury crashes was considered for three consecutive years. The road crash fatality rate for Mauritius has remained almost stagnant at around 12 per 100,000 populations for the last decade despite renewed enforcement and education measures. PTWs represented the highest transport modal share consisting of 40.4% of all motorized vehicles and also involved the highest proportion (46%) of road crash fatalities.

Given that the factors affecting crash risks would be different at intersection and non-intersection road locations [13,37], the purpose of this study was to focus on non-intersection road engineering determinants of PTW crash severity in a developing country context. Simultaneously, the aim was to consider some vehicle factors by highlighting the differences between mopeds and motorcycles with respect to road and road environment factors of crash severity. The objective was to push for a more holistic and sustainable approach to PTW riders' safety by complementing the much implemented 'enforcement' and 'education' countermeasures with road engineering measures through data-driven and evidence-based methods.

2. Materials and Methods
2.1 Data

The data for this study was obtained from police-reported crash database. For every injury accident, police officers collect the maximum of important details of the crash and the data is transferred and recorded in the database of a data management system supported by the Micro Computer Accident Analysis Package (MAAP 5) software which was developed for Mauritius by the Traffic Research Laboratory (TRL) of UK in the year 2002. The afore-mentioned database is maintained by the Traffic Management and Road Safety Unit (TMRSU) of the Ministry of Public Infrastructure of Mauritius from where the actual data was retrieved.

2.2 The Response Variable

The response variable for this study was the 'injury severity' of PTW injury crashes in Mauritius for the years 2014, 2015 and 2016. A total of 4826 PTW injury crashes was reported in Mauritius for the three-year period. Due to incomplete information in police records, 4726 fully-detailed cases were obtained. After further sorting, 3103 crashes (54%) were found to be non-intersection type crashes and were used for this investigation. Of these, about 65% were moped crashes and 35% were motorcycle crashes.

In Mauritius, the injury severities are commonly assessed by police officers at the crash scene and also with reference to the medical report of the crash victim from medical institutions. Three level of injury severities are defined, namely; fatal injury, serious injury and slight injury. A fatal injury crash is defined as one where death occurred within 30 days of sustaining injury. A serious injury crash is one whereby an injured person is hospitalized for more

than 24 hours and a slight injury crash is defined as one whereby a person receives medical care but is not admitted to hospital for more than 24 hours. The three afore-mentioned injury severity categories were redefined into two categories by collating the fatal and serious injury cases together into a single category; the 'severe injury' category and the second category was the 'slight injury' cases.

2.3 The Explanatory Variables

By aggregating the crash and casualty injury profiles, the explanatory variables reflecting the road variables (road alignment and road hierarchy), environment variables (lighting condition, weather condition, crash time and crash day) and also the crash characteristics (PTW manoeuvre, crash type, collision partner and occurrence of a pillion rider) were collectively extracted. The same predictors were used for separate analysis for moped and motorcycle crashes as detailed in Table 3.2 and Table 3.3.

2.4 Statistical Analysis
2.4.1 Descriptive statistics and Chi-squared test of Independence.

The characteristics of motorcycle and moped crashes which occurred at non-intersection location, were determined in terms of crash severity (severe injury vs. slight injury). The existence of statistical significant relationship between the response variable and the explanatory variables was verified using Pearson Chi-square or Fisher's exact tests if 25% of the cells had expected counts less than 5.

2.4.2 Multivariate Analysis

Logit analysis (stepwise) was used to identify the most significant risk factors, separately for motorcycle and moped crashes, at non-intersection locations which were involved in a severe injury (fatal or hospitalization > 24 hours). Logistic regression is very efficient for identifying and assessing the relative strength of relationship between categorical dependent variables and one or more independent (categorical, continuous, or both categorical and continuous) variables. Logit analysis is a special case of logistic regression in which all the predictor variables are categorical.

In logistic regression, a mathematical model of a set of explanatory variables is used to predict a logit transformation of the dependent variable. Suppose the numerical values of 0 and 1 are assigned to the two outcomes of a binary response variable. If p is the proportion of observations with an outcome of 1, then (1 - p) is the probability for an outcome of 0. The ratio p/(1 - p) is the odds and the logit is the natural logarithm of the odds, or just log odds.

For a binary response variable [38] the logistic regression model, expressed in terms of the logit transformation of the i_{th} individual's response probability, p_i (e.g., probability of severe injury), is a linear function of the vector of explanatory variables:

$$logit\ (p_i) = \ln\left[\frac{p_i}{1-p_i}\right] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ ...... + \beta_j X_j + ... + \beta_n X_n$$

where; x_j is the value of the j_{th} independent variable and β_j is the corresponding regression coefficients for the j_{th} predictor variable whereby there are a total of n predictors.

The Wald's test (p < 0.05) was used to identify individual predictors and the Hosmer-Lemeshow test was used to assess the goodness of fit of the model. The SPSS data package was used for all data extraction and statistical analysis.

3. Results
3.1 Descriptive statistics and Chi-square test

Of the total 4,726 Powered-two-wheelers (motorcycles and mopeds) crashes for the 3-year period, 3,103 (65.7%) occurred at non- intersection locations and 1,623 (34.3%) occurred at intersections. Concerning the 3,103 mid-block crashes 2,389 (77%) were motorcycle crashes and 714 (23%) were moped crashes.

3.1.1 Risk Factors for Motorcycle Severe Injury Crashes at non-intersection road segments

Of the 2,389 motorcycle crashes occurring at road mid-blocks, 529 (22.1%) were severe injury crashes and 1,860 (77.9%) were slight injury crashes. Table 3.1.1 shows the distribution of motorcycle crashes across the explanatory variables.

Table 3a Characteristics of motorcycle crashes occurring at non-intersection road segment by crash severity for period 2014-2016 - Mauritius

	CRASH SEVERITY(mid-blocks)				Chi-squared Test
	severe injury		slight injury		
	n	%	n	%	
	529	22.1	1860	77.9	
Motorcycle injury crashes (N= 2389)					
ROAD FACTORS					χ2=2.9, p=0.405
Road Alignment	8	1.5	20	1.1	
Longitudinal grade (straight)	18	3.4	53	2.8	
Longitudinal grade with horizontal curve	50	9.5	144	7.7	
Horizontal curve (level)	453	85.6	1643	88.3	
Straight and level					χ2=6.2, p=0.046
Road Hierarchy	35	6.6	106	5.7	
Dual carriageway	24	4.5	140	7.5	
One-way road	470	88.8	1514	81.4	
Two-way road					
ENVIRONMENTAL FACTORS					χ2=0.1, p=0.775
Weather condition	492	93.0	1726	92.8	
Clear	37	7.0	134	7.2	
Rainy/fog/Smoke/Dust					χ2=17.4, p=0.001
Light condition	53	10.0	139	7.5	
Dark (no lighting/unlit)	40	7.6	184	9.9	
Dawn/Dusk	290	54.8	1149	61.8	
Daylight	146	27.6	388	20.9	
Road lighting					
Crash Day	189	35.7	569	30.6	χ2=5.0, p=0.026
Weekends	340	64.3	1291	69.4	
Weekdays					χ2=46.7, p<0.0001
Crash Time	98	18.5	506	27.2	
10:00 - 14:59	44	8.3	52	2.8	
00:00 – 04:59	96	18.1	359	19.3	
05:00 - 09:59	194	36.7	663	35.6	
15:00 - 19:59	97	18.3	280	15.1	
20:00 - 23:59					
CRASH CHARACTERISTICS					χ2=19.2, p=0.002
Collision Partner	90	17.0	403	21.7	
Pedestrian or animal	24	4.5	57	3.1	
Heavy goods vehicle/Bus	39	7.4	100	5.4	
Powered-two-wheeler (PTW)	49	9.3	126	6.8	
Light goods vehicle (van)	159	30.1	660	35.5	
Ran off-road/hit object	168	31.8	514	27.6	
Passenger car					

PTW Manoeuvre	17	3.2	42	2.3	χ2=4.2, p=0.244
Merging/Diverging (same side)	418	79.0	1538	82.7	
Forward	20	3.8	61	3.3	
Right-turn	74	14.0	219	11.8	
Overtaking					χ2=44.4, p<0.0001
Crash Type	34	6.4	176	9.5	
Side Swipe	90	17.0	399	21.5	
Hit Pedestrian/Animal	18	3.4	82	4.4	
Rear Impact	27	5.1	97	5.2	
Right-angle Impact	159	30.1	662	35.6	
Ran off-road/Hit object	201	38.0	444	23.9	
Head On					χ2=11.9, p=0.001
Pillion Rider	416	78.6	1580	84.9	
No pillion rider	113	21.4	280	15.1	

Severe motorcycle crashes at mid-blocks were unevenly distributed across most factors of interest. The majority of severe injury crashes were found to occur on straight and level (85.6%) however, the road alignment was not significantly related to crash severity (p=0.405). The road hierarchy was significantly associated with severity of injury (p=0.046) whereby 88.8 % of severe injury crashes occurred on two-way road. It was observed that a high percentage (93%) of high severity crashes occurred under fine weather conditions but this factor was not significantly associated with the severity of crashes (p=0.775). Concerning the light condition factor, the largest proportion of severe injury crashes occurred during daylight (54.8%) however a relatively important proportions occurred during night hours under road lighting conditions (27.6%) and in the dark (10%) whereby no road lighting was provided or it was unlit. The light condition was significantly associated with severe injury outcome (p= 0.001). On a daily basis more severe crashes occurred during weekends (35.7% for two days) as compared to weekdays (64.3% for five days). The crash day was significantly associated with injury severity (p=0.026). The majority of severe injury crashes occurred during the afternoon peak hours, 15.00 – 19.59 (36.7%) whereby significant equal proportions crashed during daytime off-peak hours (18.5%), morning peak hours (18.1%) and night off-peak hours (18.3%). The crash time factor was significantly associated with severe injury outcome of motorcycle crashes (p<0.0001). Concerning crash partner, crashes with passenger cars (31.8%) and loss-of-control crashes (30.1%) were found to have almost equal and highest frequencies of severe crashes followed by hitting pedestrians or animals (17%). The crash partner factor was identified to be significantly associated with severity of crashes (p= 0.002). Most of the severe crashes occurred when the motorcycle was effecting a forward movement (79%) whereby it must be pointed out that the overtaking manoeuvre also involved in a relatively important proportion (14%) of severe crashes. However, the motorcycle manoeuvre was not associated with severity of crashes (p=0.244). Regarding the crash type factor, head on (38%) and loss-of control crashes (30.1%) accounted for the two highest proportions of severe injury crashes with a relatively important proportion of severe crashes involved hitting pedestrians or animals (17%). The crash type factor was found to be significantly associated with severity of crashes (p<0.0001). It was also observed that most severe crashes occurred in the absence of a pillion rider (78.6%) on the motorcycle whereby the pillion rider factor was also found to be significantly associated with severity of crashes (p=0.001).

3.1.2 Factors associated with Slight Injury Crash Risk factors for Motorcycles at non-intersection road segments in Mauritius

Slight motorcycle crashes at mid-blocks were also unevenly distributed and followed the similar distribution pattern as severe injury crashes across many factors of interest. Concerning road alignment

and hierarchy, a slightly higher percentage of slight injury crashes were found to occur on straight and level (88.3%), and one-way roads (7.5%) relative to severe injury crashes. The dominant proportion of slight injury crashes occurred during fine weather and were almost equal (92.7%) to that of severe injury crashes (93.0%). Regarding the light condition factor, similar to severe injury crashes the highest proportion of slight injury crashes occurred during daylight (61.8%). Considering only the two most important categories for light conditions namely, road lighting during darkness hours and daylight, it was observed that for severe crashes 50% occurred under road lighting at night whereas it was only 33% for slight injury crashes. Also, a slightly higher percentage of slight injury crashes (9.9%) happened during dawn/dusk hours. The afore-mentioned findings tally with the crash time factor whereby remarkably higher proportions of slight injury crashes occurred during daylight (61.8%) whereby only 2.8% and 15.1% of slight injury crashes occurred during dark hours between 00:00 - 04:59 and 20:00 – 23:59 respectively. The daily rate of slight injury crashes for motorcycles was higher during weekends (30.6% for two days) as compared to weekdays (69.4% for five days). Even though single vehicle crashes were highly significant for both severe and slight injury crashes, these loss-of-control crashes, of which about 38% involved collision

with a road-side object, were found to be more pronounced for slight injury impacts representing 35.5% of crashes. A higher percentage of slight injury crashes involved collision with pedestrian or stray animals and passenger cars were involved in fewer slight injury crashes relative to severe injury ones. A slightly higher proportion of slight injury crashes occurred when motorcycles were effecting a forward movement (82.7%) whereby lesser proportion of overtaking manoeuvres (11.8%) caused slight injury crashes. There were a lesser proportion of head-on crashes (23.9%) with slight injury outcomes. It was also observed that a higher proportion of slight injury crashes occurred when the motorcycle was carrying a passenger whereby the pillion rider factor was significantly associated with severity of crashes.

3.1.3 Risk Factors for Mopeds Severe Injury Crashes at non-intersection road segments

Of the 714 moped crashes occurring at road mid-blocks, 157 (22%) were severe injury crashes and 557 (78%) were slight injury crashes. Table 3.1.2 shows the distribution of moped crashes across the explanatory variables.

Table 3b Characteristics of moped crashes occurring at non-intersection road segment by crash severity for period 2014-2016 - Mauritius

	MOPED - CRASH SEVERITY (mid-block)				Chi-squared Test
	severe injury		slight injury		
	n	%	n	%	
Moped injury crashes (N= 714)	157	22.0	557	78.0	
ROAD FACTORS					
Road Alignment					χ2=7.7, p=0.049
Longitudinal grade (straight)	6	3.8	10	1.8	
Longitudinal grade with horizontal curve	4	2.5	17	3.1	
Horizontal curve (level)	22	14.0	45	8.1	
Straight and level	125	79.6	485	87.1	
Road Hierarchy					χ2=0.2, p=0.889
Dual carriageway	4	2.5	16	2.9	
One-way road	10	6.4	41	7.4	
Two-way road	143	91.1	500	89.8	
ENVIRONMENTAL FACTORS					
Weather condition					

Clear	147	93.6	517	92.8	χ2=0.1, p=0.860
Rainy/fog/Smoke/Dust	10	6.4	40	7.2	
Light condition					χ2=14.9, p=0.002
Dark (no lighting/unlit)	21	13.4	43	7.7	
Dawn/Dusk	19	12.1	76	13.6	
Daylight	75	47.8	344	61.8	
Road lighting	42	26.8	94	16.9	
ENVIRONMENTAL FACTORS (TEMPORAL)					
Crash Day					χ2=0.3, p=0.631
Weekends	49	31.2	187	33.6	
Weekdays	108	68.8	370	66.4	
Crash Time					χ2=11.1, p=0.025
10:00 - 14:59	30	19.1	158	28.4	
00:00 - 04.59	6	3.8	12	2.2	
05:00 - 09:59	31	19.7	105	18.9	
15:00 - 19:59	55	35.0	205	36.8	
20:00 - 23:59	35	22.3	77	13.8	
CRASH CHARACTERISTICS					
Collision Partner					χ2=5.2, p=0.268
Pedestrian or animal	11	7.0	72	12.9	
Heavy goods vehicle/Bus	17	10.8	77	13.8	
Powered-two-wheeler (PTW)	14	8.9	80	14.4	
Light goods vehicle (van)	14	8.9	41	7.4	
Ran off-road/hit object	55	35.0	127	22.8	
Passenger car	46	29.3	160	28.7	
PTW Manoeuvre					χ2=8.4, p=0.037
Merging/Diverging (same side)	0	0.0	19	3.4	
Forward	124	79.0	451	81.0	
Right-turn	9	5.7	31	5.6	
Overtaking	24	15.3	56	10.1	
Crash Type					χ2=15.7, p=0.003
Side Swipe	14	8.9	76	13.6	
Hit Pedestrian/Animal	11	7.0	72	12.9	
Rear Impact	8	5.1	0	0.0	
Right-angle Impact	14	8.9	60	10.8	
Ran off-road/Hit object	44	28.0	113	20.3	
Head On	66	42.0	136	24.4	
Pillion Rider					χ2=0.03, p=0.899
No pillion rider	135	86.0	476	85.5	
Pillion rider	22	14.0	81	14.5	

Severe moped crashes at non-intersection segments of the road were unevenly distributed across most factors of interest. The majority of severe injury crashes were found to occur on straight and level roads (79.6%) with a relatively important proportion on horizontal curves (14%). The road alignment factor

was significantly related to moped crash severity (p=0.049). Concerning the road hierarchy and weather condition variables the highest proportion of severe crashes occurred on two-way roads (91.1%) and during fine weather (93.6%) but there were no significant association between these two variables to severity of moped crashes (p=0.889 and p=0.86 respectively). Concerning the light condition factor, the largest proportion of severe injury crashes occurred during daylight (47.8%) however relatively important proportions occurred under road lighting conditions (26.8%), in the dark (13.4%) whereby no road lighting was provided or it was unlit and during dawn/dusk hours (12.1%). The light condition was significantly associated with severe injury outcome for mopeds (p= 0.002). The crash day was not significantly associated with injury severity (p=0.631) whereby 68.8% of severe crashes occurred on weekdays. The majority of severe injury crashes occurred during the afternoon peak hours, 15.00 – 19.59 (35%) followed by night-time off-peak hours (22.3%) and almost equal proportions crashed during morning peak hours (19.7%) and daytime off-peak hours (19.1%). The crash time factor was significantly associated with severe injury outcome of moped crashes (p=0.025). The crash partner factor was not significantly associated with severe moped crashes (p=0.268), nevertheless loss-of-control crashes were involved with 35% of severe crashes. Most of the severe crashes occurred when the mopeds were effecting a forward movement (79%) whereby it must be highlighted that the overtaking manoeuvre also involved in a relatively important proportion (15.3%) of severe crashes. The moped manoeuvre factor was associated with severity of crashes (p=0.037). Regarding the crash type factor, head on (42%) and loss-of control crashes (28%) accounted for the two highest proportions of severe injury crashes with a relatively important proportion of severe crashes involved crashes with heavy goods vehicles or buses (10.8%). The crash type factor was found to be significantly associated with severity of crashes (p=0.003). It was also observed that most severe crashes occurred in the absence of a pillion rider (86%) on the moped whereby the pillion rider factor was found not to be significantly associated with severity of crashes (p=0.899).

3.1.4 Factors associated with Slight Injury Crash Risk factors for Mopeds at non-intersection road segments in Mauritius

Slight injury moped crashes at non-intersection segments of the road were also unevenly distributed across most factors of interest. Concerning the road alignment, the majority of slight injury crashes were found to occur on straight and level roads (87.1%). A remarkably lesser proportion of slight injuries were sustained for crashes on horizontal curves (8.1%) relative to severe crashes (14%) on the same alignment. Concerning the road hierarchy and weather condition variables the distribution of slight injury crashes was similar to severe injury crashes with the highest proportion occurring on two-way roads (89.8%) and during fine weather (92.8%). Concerning the light condition factor for mopeds, the largest proportion of slight injury crashes occurred during daylight (61.8%). Regarding the two most important categories for light conditions namely, road lighting during darkness hours and daylight, it was observed that for severe crashes 56% occurred under road lighting at night whereas it was only 27% for slight injury crashes. Relatively important proportions of slight injury crashes occurred during dawn/dusk hours (13.6%). The afore-mentioned findings correspond with the crash time factor whereby remarkably higher proportions of slight injury crashes occurred during daylight (61.8%) whereby only 2.2% and 13.8% of slight injury crashes occurred during dark hours between 00:00 - 04:59 and 20:00 – 23:59 respectively. The daily rate of slight injury crashes for mopeds was higher during weekends (33.6% for two days) as compared to weekdays (66.4% for five days). Concerning the crash partner factor for mopeds, the most important factors were found to be different for severe injury crashes which emerged to be loss-of-control crashes (35.0%) whereas for slight injury crashes it was identified to be passenger cars (28.7 %). Slight injury crashes due to loss-of-control accounted for 22.8% of cases. Relatively higher proportions of slight injury crashes occurred involving collision with pedestrian or animals (12.9%), heavy goods vehicles/buses (13.8%) and other powered-two-wheelers (14.4%). Most of the slight injury crashes occurred when the mopeds were effecting a forward movement (81%) whereby relatively lesser proportion (10.1%) as compared to severe crashes involved the overtaking manoeuvre. Relatively fewer

proportion of head-on crashes (24.4%) were involved with slight injuries. It was also observed that most slight injury crashes occurred in the absence of a pillion rider (85.5%) on the moped.

3.2 Risk factors associated with severe injury motorcycle crashes at non-intersection road segments.

Table 3c shows the factors associated with severe injury motorcycle crashes at non-intersection road segments in Mauritius determined using a logistic regression analysis

Table 3c Risk factors associated with severe injury motorcycle crashes at non-intersection road segments (sample size = 2389)

	B	p	Odds Ratio	95% of CI	
				Lower	Upper
Road Hierarchy					
Dual carriageway*					
One-way road	-0.642	0.033	0.526	0.292	0.948
Two-way road	-0.206	0.327	0.814	0.539	1.229
Crash Time					
10:00 - 14:59*					
00:00 - 04.59	1.566	< 0.0001	4.787	2.994	7.654
05:00 - 09:59	0.348	0.031	1.417	1.032	1.945
15:00 - 19:59	0.401	0.004	1.493	1.137	1.96
20:00 - 23:59	0.546	0.001	1.726	1.25	2.384
Light condition					
Dark (no lighting/unlit)*					
Dawn/Dusk	-0.124	0.508	0.883	0.611	1.277
Daylight	0.456	0.011	1.578	1.112	2.239
Road lighting	0.428	< 0.0001	1.534	1.215	1.938
Pillion Rider					
No pillion rider*					
Pillion rider	0.369	0.004	1.446	1.125	1.857
Crash Type					
Side Swipe*					
Hit Pedestrian/Animal	0.109	0.627	1.115	0.718	1.731
Rear Impact	0.358	0.218	1.43	0.809	2.526
Right-angle Impact	0.172	0.590	1.188	0.635	2.221
Ran off-road/Hit object	0.061	0.014	1.963	1.701	3.61
Head On	0.796	< 0.0001	2.218	1.471	3.344
Collision Partner					
Pedestrian or animal*					
Heavy goods vehicle/Bus	0.550	0.014	1.733	1.118	2.687
Powered-two-wheeler (PTW)	0.512	0.013	1.668	1.112	2.502
Light goods vehicle (van)	0.360	0.015	1.433	1.072	1.916
Ran off-road/hit object	0.654	0.016	1.924	1.127	3.282
Passenger car	-0.001	0.993	0.999	0.746	1.337

* denotes the reference category

The significant risk factors for motorcycle severe injury crashes at road mid-blocks were found to be; the road hierarchy, the crash time, the light condition, the occurrence of a pillion rider, the crash type and the collision partner (Table 3c). For motorcycles, when crashes occurred on one-way roads the odds of sustaining severe injury was 48% lower than crashes which occurred on dual carriageways. Results also showed that relative to crashes which occurred in the time range 10.00 – 14.59, the odds of severe injury crashes increased ; by 378.7% between 00.00 – 04.59, by 41.7% between 05.00 - 09.59, by 49.3% between 15.00 – 19.59 and by 72.6% between 20.00 – 23.59. Compared to crashes which occurred in the dark, the odds of sustaining severe injury increased by; 57.8% for crashes which occurred during daylight and by 53.4% for crashes which occurred under road lighting

conditions. Carrying a pillion rider increased the odds of severe injury crashes by 44.6%.

Compared to sideswipe crashes, head-on crashes had significantly higher odds of severe injury (OR= 2.218). Relative to collision with pedestrians or animals, crashes with heavy goods vehicles or buses/other PTWs/light goods vehicles and loss-of-control crashes had significantly higher odds of severe injury (OR: 1.4~1.9).

3.3 Risk factors associated with severe injury moped crashes at non-intersection road segments.
Table 3d shows the factors associated with severe injury moped crashes at non-intersection road segments in Mauritius determined using a logistic regression analysis.

Table 3d Risk factors associated with severe injury moped crashes at non-intersection road segments (sample size= 714)

	B	p	Odds Ratio	Lower	95% of CI Upper
Road Alignment					
Longitudinal grade (straight)*					
Longitudinal grade with horizontal curve	0.784	0.149	2.19	0.755	6.356
Horizontal curve (level)	0.736	0.012	2.088	1.173	3.718
Straight and level	-0.079	0.894	0.924	0.292	2.928
Crash Time					
10:00 - 14:59*					
00:00 - 04.59	0.943	0.091	2.567	0.860	7.663
05:00 - 09:59	0.457	0.120	1.579	0.887	2.809
15:00 - 19:59	0.405	0.116	1.499	0.905	2.481
20:00 - 23:59	0.958	0.001	2.606	1.452	4.678
Light condition					
Dark (no lighting/unlit)*					
Dawn/Dusk	0.161	0.584	1.175	0.66	2.091
Daylight	0.774	0.012	2.169	1.184	3.971
Road lighting	0.791	0.001	2.206	1.387	3.509
Crash Type					
Side Swipe*					

Hit Pedestrian/Animal	-0.147	0.711	0.863	0.397	1.877
Right-angle Impact	0.272	0.524	1.313	0.569	3.029
Ran off-road/Hit object	0.396	0.264	1.486	0.742	2.978
Head On	0.885	0.009	2.423	1.243	4.722

* denotes the reference category

Significant risk factors for moped severe injury crashes at road mid-blocks were; the road alignment, the crash time, the light condition and the crash type (Table 3.5). For mopeds, when crashes occurred on horizontal curves the odds of sustaining severe injury was 108.1% higher than crashes which occurred on straight roads with longitudinal grades. Results also showed that relative to crashes which occurred in the time range 10.00 – 14.59, the odds of severe injury crashes increased by 160.6% between 20.00 – 23.59. Compared to crashes which occurred in the dark, the odds of sustaining severe injury increased by; 116.9% for crashes which occurred during daylight and by 120.6% for crashes which occurred under road lighting conditions. Compared to sideswipe crashes, head-on crashes had significantly higher odds of severe injury (OR= 2.423).

4. Discussion

This study attempted to focus on the road engineering determinants of motorcycle and moped crashes which occurred along non-intersection road segments during the years 2014, 2015 and 2016 in Mauritius. Common contributory factors of severe injury crashes for both motorcycle and moped crashes included crash time, crash type and light condition. However, some differences were observed regarding the categories for the crash time factors. For motorcycles the time range 00.00-04.59 was found to have the highest odds of severe crashes and all other time ranges were also significant with almost equal lower odds whereas for mopeds the only time range 20.00 – 23.59 was found to be highly risky. For both of these time ranges, the increased risk of severe crashes may be explained by the reduced conspicuity problem under road lighting conditions as highlighted in previous research [9,29,31] and also the increased possibility for speeding at such odd hours due to minimum traffic and reduced traffic control measures.

Head-on crashes on non-intersection road segment may be attributed to overtaking manoeuvres whereby visibility, road marking, delineation and geometrical design with regard to provision for overtaking possibilities were inadequate. For both motorcycles and mopeds, riding under daylight and road lighting conditions were found to be highly significant for increased risk of severe injuries relative to riding in the dark. Here, surely it may not imply that daylight and road lighting conditions were worse than dark/unlit roads. The reference category, dark/unlit road are less busy road with much fewer traffic whereby other factors like traffic conditions may influence the level of visibility for daylight conditions and the relatively reduced illumination for road lighting conditions at night. Nevertheless, it must be also pointed out that since the year 2014 wearing of retroreflective jackets during nighttime and use of dipped headlights at all times are compulsory for all PTW riders in Mauritius.

Factors specific to motorcycles associated which increased risks of severe injury at road mid-block locations included riding on one-way roads, dual-carriageways, carrying a passenger and hitting the following; heavy goods vehicles or buses, or other PTWs, or light goods vehicles or ran off-road crash types which may include hitting an object crashes (the reference category was hitting pedestrian or animal). The afore-mentioned one-way road factor may be attributed to the number of lanes, lane width and shoulder width characteristics which have been highlighted in a previous study [39]. Though 88.8% of severe motorcycle crashes occurred along two-way roads, the dual-carriageways and one-way roads were found to be more likely to increase severity of motorcycle crashes. Thus all road hierarchies considered were hazardous for motorcycles in Mauritius. Regarding the other crash partners except other PTWs, the interaction of motorcycles with larger/heavier vehicles whereby the latter produces

much more kinetic energy and thus magnify crash severity corroborates with earlier findings [40]. Concerning crashes with other PTWs the high risk of severe injury can be explained by the fact that the drivers of both PTWs being physically unprotected as compared to automobile drivers. Concerning pillions, it is acknowledged that motorcycles rely on balance for stability. Thereby, carrying a pillion rider affect the balance by changing the centre of gravity of the whole mass and thus influence the stability of the vehicle. If a motorcycle passenger fidgets, moves about or leans the opposite way to the bike while cornering, it would create a hazard that may become so severe that the motorcyclist cannot compensate and result in a crash. Thus, a pillion rider can trigger a motorcycle crash if the latter do not have sufficient knowledge of the technicalities in order to cooperate adequately with the PTW driver. Motorcycle 'ran off-road/hit object' crashes have been associated with the sensitivity of such two-wheelers to the road surface conditions. The consistent grip of the tyres on the road surface is critical to the stability of a two wheeled vehicle and for the rider's control of the machine. Road surface conditions, such as surface defect; potholes, ruts, cracks, loose gravel, faulty manhole covers etc. are highly hazardous regarding motorcycle loss-of-control crashes. Subsequent to loss-of-control crashes more severe injuries can be sustained by riders as a result of impact with a roadside object during the course of the crash. Thus the relatively increased vulnerability of motorcyclists to roadside objects is a life-saving issue whereby the forgiving roadside concept need to be maximized [41, 42].

Factors specific to mopeds associated which increased risks of severe injury at road mid-block locations was riding on horizontal curves. The field of vision are deemed to be limited on roads with horizontal curves. It has been reported that the radius, the length and the shoulder width of curves are significant factors contributing to the occurrence and severity of PTW crashes [23].

5. Conclusion

This study identified some road engineering determinants which increased the risk of fatal and serious injury crashes for mopeds and motorcycles at non-intersection road segments in Mauritius. Some differences were observed regarding crash severity factors between mopeds and motorcycles. Motorcycles were not affected by the road alignment as were mopeds. The road hierarchy, the existence of a pillion rider and ran off-road/hit object (loss-of-control) crashes did not affect crash severity for mopeds as was the case with motorcycles.

The following factors were reported to be associated with a significantly higher probability of fatalities and severe injuries for both PTW types; the light condition, riding during off-peak hours early morning and at night and head-on crashes. Overall road engineering determinants which were deduced to be pivotal regarding increased PTW crash severity were defective road surface, inadequate road lighting and unforgiving roadsides.

The results of this study can be used by road authorities to improve road safety along non-intersection road segments in similar developing countries, particularly for PTW riders. This study highlights that the engineering of the road surface and environment can have a significant impact on the likelihood and severity of a crash. Hazards in the road environment can be reduced through road maintenance procedures. It is important that all those involved in the design, construction and maintenance of the road environment are more aware of the specific needs of mopeds and motorcycles. Treatments should include improved road lighting, better signage on curves, enhanced delineation, improvements to road surfaces and provision of more PTW friendly and forgiving roadside.

5.1 Study limitations

The independent variables used for this study was based on police-reported mopeds and motorcycles injury crashes which provided road engineering details (variables) at the macro-level. For example, details about the frictional property of the road surface or the quality of road signage which are road engineering particulars at micro-level, are not obtainable in police-reported data. Nevertheless, we believe that the findings from this research remain relevant and useful whereby inclusion of other micro-level detailed road engineering variables in future research would add-on to the actual findings.

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