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Analysis of the effect of directional traffic volume and mix on road traffic crashes at three-legged unsignalized intersections

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ABSTRACT

Traffic volume is the most common factor associated with road traffic crash frequency. Use of aggregate volume measures may lead to biased prediction of crash frequencies. Disaggregate analysis that involve hourly volumes can better explain this effect. In low and middle-income countries traffic mix may vary with respect to direction of travel on a road and such variation in proportion leads to crashes and conflicts among crossing vehicles at unsignalized intersections. This paper aims to explore the above relationship in the context of three-leg unsignalized intersections in Malaysia. First exploratory analysis of geometric and traffic variables was performed and their relationship with the crash frequency and type of conflicts was examined. Then probability of crashes was calculated with respect to the percentage of motorcycles that moved in a certain direction and proportion between volume in each direction. Segregation of the data with respect to traffic direction and traffic mix indicated that sites with less percentage of motorcycles moving in the far side direction experienced more crashes as compared to sites with greater percentage of motorcycles moving in the far side direction, given the condition that the volume ratio between each direction was larger than one. Results showed that the chances of crashes and serious conflicts increased upto 25% and 67% respectively; as the percentage of motorcycles that moved in the far side direction decreased from 31%, subject to the condition that the ratio of volume between each direction remained greater than one. It was concluded that traffic mix and traffic volume together influence the crash frequency at unsignalized intersections.

1. Introduction

Traffic safety is always the top priority in the area of road transportation [1] and safety aspects such as estimation of road traffic crashes are part of most transportation engineering projects. The road traffic crashes depend on several factors, such as volume [2], speed [3], geometry, weather and site conditions [4]. Traffic volume is one of the most important amongst the predictor variables for crash frequencies [5]. Effect of volume on the crash occurrence at unsignalized intersections can be analyzed both at the aggregate level such as Annual Average Daily Traffic (AADT) as well as disaggregate level such as hourly volumes. But disaggregate analysis is more powerful in the explanation of the causes of crashes pertinent to each site as evident from the results of a previous study [6] which highlighted the importance of hourly traffic volume on the measure of crashes in association with the uniqueness of each roadway section. It is a well established fact that the number of crashes is a function of exposure, that is, they are dependent upon the volume of traffic [7]. Common crash rates are measured in terms of the annual number of crashes based on the annual amount of exposure [6]. The proportionality between them has been argued in the literature and the relationship has been explained. Both simple as well as complex models have indicated a positive association of traffic volume with crash frequencies [8,9,10,11,12,13].

Apart from volume, the composition of vehicles that utilize any roadway facility also plays an important role in its safety. Unsignalized intersections are no exception. It has been reported that the risk of the road users such as pedestrians, motorized and non-motorized vehicles vary greatly with respect to traffic mix [14]. In developing countries, the road usage and traffic mix is often very different from that of more industrialized countries [15]. That is the reason why in these countries, traffic mix is one of the factors that contribute towards the high rate of crashes [16]. In India, the increase in the risk of fatal crashes per percent increase in the population of two-wheelers in the traffic mix is twice as much as compared to the increase in the risk of fatal crashes per percent increase in the population of four-wheelers [17]. Hence, both the traffic mix and the traffic volume are considered as variables that effect crash frequency but their combined contribution on the occurrence of crashes has not been explored extensively within the domain of unsignalized

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intersections in the literature. In most Asian countries like China, India, Pakistan, Malaysia, Indonesia, Nepal, Taiwan, Thailand, Vietnam, Cambodia and Philippines [8], the traffic mix is highly heterogeneous with motorcycles accounting upto 95% of the total number of registered vehicles. Therefore, the two important groups in the analysis of crash frequencies with respect to traffic mix are the percentage of motorcycles and the percentage of other vehicles. An example of such approach is the study conducted by Harnen et al. [12] that utilized motorcycle and non-motorcycle flows of major and minor roads for the development of crash prediction models for unsignalized intersections in Malaysia.

The unique behavior of vehicles at intersections which is indigenous to low and middle-income countries makes crash occurrence a function of traffic mix given that there exists a difference in traffic volume that moves in opposite direction on the major road. This paper aims to explore the above relationship with respect to the crashes and conflicts that occurred at three-leg unsignalized intersections in Malaysia. First exploratory analyses were performed to examine the effect of directional volume and traffic mix on the crash frequency. Conditional probability of crashes was then calculated with percentage of motorcycles that moved in the far side direction and near to far volume ratio as the corresponding two events of the total three events involved in the conditional analysis. At times traffic conflicts are utilized as surrogate measure of risk [18] associated with a particular intersection to supplement the results of the analysis performed with respect to crashes. This study also examines the conditional relationship of traffic conflicts with traffic volume and mix and comparison between the results obtained with respect to crashes and conflicts is presented.

2. Methodology

2.1. Data acquisition and segregation

Three legged unsignalized intersections located in the state of Penang, West Malaysia, were selected for this study. They constitute a huge number among all the fixed control facilities provided on the Road Infrastructure of Malaysia [19]. Volume on all the 14 sites was collected using MetroCount MC 5600 [20]. The data was collected during morning peak hours from 6:30 p.m. to 9:30 p.m. on all legs of each intersection. Crash frequency was chosen as the response variable while the four primary explanatory variables used in the analysis were Road width, Volume, Speed and Gap/Spacing between vehicles. Volume was further subdivided into 13 variables, namely: near to far volume ratio, percent motorcycle far side, total percent motorcycle, volume motorcycle near, volume motorcycle far, total volume motorcycle, volume other near, volume other far, total volume others, total volume near, total volume far, total volume major, total volume minor. Speed was further subdivided into ten variables, namely: speed motorcycle near, speed motorcycle far, average speed motorcycle, speed other near, speed other far, average speed other, average speed near, average speed far, average speed all and near to far speed ratio. Gap/Spacing between vehicles was further subdivided into nine variables, namely: gap motorcycle near, gap motorcycle far, average gap motorcycle, gap other near, gap other far, average gap other, average gap near, average gap far, near to far gap ratio. The process of data segregation with respect to traffic direction and traffic mix is presented in Fig. 1.

Road traffic crash data that comprised of different types of crashes, such as fatal, severe injury, slight injury and damage only, was provide by Malaysian Institute of Road Safety Research (MIROS). The data contained attributes such as major/minor road width, landuse, lane marking, and traffic control but did not contain the precise location of site where the crash occurred. Therefore, the selection of sites was based upon the output given by the "Nested Filtered Search Algorithm (NFSA)" designed for the rectification of errors occurring in the National Crash Database[36]. A total of 22 crashes were identified by the NFSA. Conflict data on six intersections, out of the 14 intersections selected for this study, was acquired using visual observation on site and through videos recorded at the same time as that of traffic data collection. Frequency of serious conflicts was chosen as the response variable for analysis with respect to conflicts while the explanatory variables were the same as the ones used in the crash analysis.

2.2. Model development

Literature pertinent to crashes involving motorcycles have proven them to be the most vulnerable group in both homogenous [21,22] as well as heterogeneous [19,23] traffic environment. Their vulnerability is primarily because of their small size and no external protection such as air bags available to other motorized vehicles like cars. Thus, the lower the percentage of non-vulnerable road user the lower the chances of them being involved in a crash with the vulnerable road user. This leads to the proposition that higher percentages of vehicles belonging to the vulnerable group, that is motorcycles, within the total volume of the major approach at an intersection will decrease the chances of crash between the minor and major road vehicles, provided that the ratio between the volume moving in the near side direction to the far side direction is greater than one. Mathematically the above relationship is written as

$$\mathrm{P(AUB|C) = P(A|C) + P(B|C) - P(A \cap B|C)} \tag{1}$$

Where,

$$\mathrm{P(A|C)} = \frac{\text{A terms common to C}}{Total\ C\ events} \tag{2}$$

$$\mathrm{P(B|C)} = \frac{\text{B terms common to C}}{Total\ C\ events} \tag{3}$$

$$\mathrm{P(A \cap B|C)} = \frac{\text{(A} \cap \text{B) terms common to C}}{Total\ C\ events} \tag{4}$$

A=Percentage of Motorcycles Far Side
B=Number of Crash(s)
C=Near to Far Volume Ratio

The model form presented in Eq. 1 is known as the conditional probability of three events, and is similar to the model form presented in Hasan and Tahar [24]. Different percentages of motorcycles that move in the far side direction represent different individual scenarios that can number as scenario 1, 2, 3 and so on. Similarly, different number of crashes, such as single, double and multiple, represent different individual scenarios that can also be number as scenario 1, 2, 3 and so on. Hence, for different individual scenarios of percentages of motorcycles that moves in the far side direction and the number of crashes that can occur at each crash site, Eqs. 1 to 4 can be generalized as

$$\mathrm{P\left(A_i U B_j|C\right) = P\left(A_i|C\right) + P\left(B_j|C\right) - P\left(A_i \cap B_j|C\right)} \tag{5}$$

Where,

$$\mathrm{P}\left(A_i|\mathrm{C}\right) = \frac{A_i \text{ terms common to C}}{Total\ C\ events} \tag{6}$$

$$\mathrm{P}\left(B_j|\mathrm{C}\right) = \frac{B_j \text{ terms common to C}}{Total\ C\ events} \tag{7}$$

$$\mathrm{P}\left(A_i \cap B_j|\mathrm{C}\right) = \frac{\left(A_i \cap B_j\right) \text{ terms common to C}}{Total\ C\ events} \tag{8}$$

A_i = Percentage of Motorcycles Far Side i=1,2,3.......n
B_j = Number of Crash(s) j=1,2,3.......n
C = Near to Far Volume Ratio

For this study the conditional probability analysis was performed both with respect to crashes as well as conflicts. The conditional probability for single and double crashes (characterized as event 'B') was calculated for two scenarios, that are, the percentages of motorcycle is less

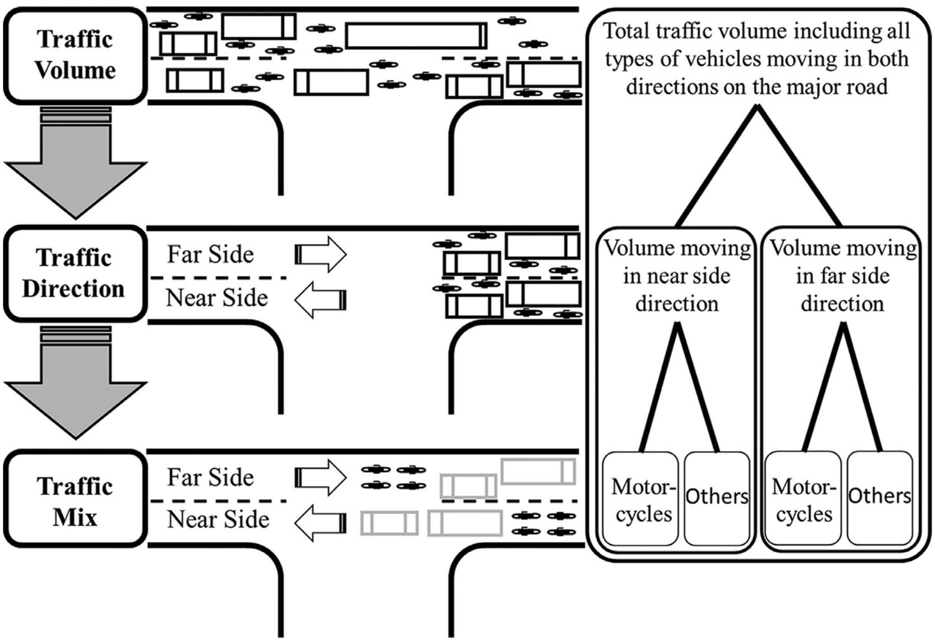

Fig. 1. Segregation of data with respect to traffic direction and traffic mix.

Table 1
Event description, coding and scenario.

Event description	Event coding	Scenario
Analysis with respect to Crashes		
Percentage of Motorcycles Far Side	A	> 31
		< 31
Number of Crashes	B	= 1
		= 2
Near to Far Volume Ratio	C	> 1
Analysis with respect to Conflicts		
Percentage of Motorcycles Far Side	A	> 31
		< 31
Number of Serious Conflicts	B	= 1
		> 1
Near to Far Volume Ratio	C	> 1

than 31% and greater than 31% (characterized as event 'A') provided that the near to far volume ratio remains greater than one (characterized as event 'C'). Similarly, the conditional probability for single and multiple serious conflicts (characterized as event 'B') was also calculated for two scenarios, that are, the percentages of motorcycle is less than 31% and greater than 31% (characterized as event 'A') provided that the near to far volume ratio remains greater than one (characterized as event 'C') as shown in Table 1.

From the traffic data collected it was found that the percentage of motorcycles in the volume of traffic moving in the 'Far Side' direction ranged between 20% and 67%. In most low and middle-income Asian countries, the percentage of motorcycles amongst the registered vehicles is above 30% [25]. This gave rise to the dissection of data with respect to the share of motorcycles in the traffic volume moving in a particular direction. Therefore, upon arranging the sites with respect to percentage of motorcycles far side, it was found that sites with percentage greater than 31% experienced fewer number of multiple accidents as compared to sites with percentage lesser than 31%. Hence, this value was selected as the threshold value for the two scenarios of event A. In the analysis related to crashes, all the sites experienced either one crash or two crashes only. This defined the values for the two scenarios of event B. Similarly, in the analysis related to traffic conflicts, all the sites experienced either one serious conflict or more than one serious conflict. This defined the values for its two scenarios of event B. On all sites the ratio between near side to far side volume was either less than one or greater than one. Therefore, the value of near side to far side volume ratio greater than one was chosen for event C. It is important to note that the scenarios defined for each event are based on the collected data and hence are specific to the intersections examined in this study.

3. Results and discussion

3.1. Descriptive analysis

3.1.1. Descriptive analysis of single versus multiple crashes

The descriptive analysis of the data presented in Table 2 shows that the mean width of major road on sites with single crashes and sites with multiple crashes is the approximately same which is 12 feet. Analysis with respect to the different parameters of volume also showed similar trend except four, which were total percentage of motorcycles, total volume near, total volume far and total volume minor. The total percentage of motorcycles was found to be higher on sites with single crashes as compared to sites with multiple crashes. This indicates that greater number of motorcycles in the traffic mix decreases the risk of crashes at unsignalized intersections. Although the total volume on the major approach was nearly the same for both the sites having single and multiple crashes respectively, but the difference between the volume flowing in the near side and far side direction was found to be significant on sites with multiple crashes. Moreover, the mean far side volume was higher than the mean near side volume on both types of sites. Significant difference was observed between the mean volumes on the minor approaches of the two types of sites. Examination of the different parameters of speed also showed no variation among the two types of sites. The only important finding was that the mean values of nine parameters of speed, which were: speed motorcycle near, speed motorcycle far, average speed motorcycle, speed other near, speed other far, average speed other, average speed near, average speed far, and average speed all; were found to be higher on sites with multiple crashes as compared to sites with single crashes. This is in line with the established fact in transportation engineering that increase in speed increases the number and severity of crashes [26].

Investigation of the gap or spacing between vehicles indicated that there was not much difference between the gap among motorcycles or other vehicles or both moving in the near side direction and the far side direction on sites with single crashes. But on sites with multiple crashes the difference was prominent. This clearly shows that the variation in

Table 2
Descriptive statistics of sites with single and multiple crashes.

		Sites having Single Crash				Sites having Multiple Crashes			
		Mean	S.D	Min	Max	Mean	S.D	Min	Max
Crash Frequency		[a]	[a]	[a]	[a]	3	1.15	2	4
Road Width		11.58	2.73	7.1	15	12.03	2.70	8.3	14.5
Volume	Near to Far Volume Ratio	1.02	0.48	0.43	1.9	1.55	0.40	1.08	2.01
	Percent MC Far Side	38.66	14.20	19.95	66.79	33.18	10.19	23.65	47.62
	Total Percent MjC	37.59	13.89	21.46	65.46	30.43	7.97	21.35	40.19
	Volume MC Near	660	321	236	1269	703	497	185	1357
	Volume MC Far	710	307	165	1226	592	513	109	1313
	Total Volume MC	1370	556	401	2266	1296	1007	294	2670
	Volume Other Near	1476	1160	161	3518	1774	1229	527	3088
	Volume Other Far	1452	1009	173	3339	1088	653	245	1734
	Total Volume Others	2927	1905	334	5203	2862	1863	772	4822
	Total Volume Near	2136	1398	446	4365	2477	1640	712	3887
	Total Volume Far	2162	1221	348	4171	1680	1062	354	2757
	Total Volume Major	4297	2335	868	7148	4157	2678	1066	6644
	Total Volume Minor	209	484	3	1569	44	42	2	81
Speed	Speed MC Near	36.33	9.99	20.47	54.9	37.05	6.72	27.35	42.77
	Speed MC Far	38.28	9.37	27.86	60.61	41.16	8.16	31.14	49.49
	Average Speed MC	37.30	9.50	24.17	57.76	39.10	7.31	29.25	46.13
	Speed Other Near	35.44	11.51	17.93	56.4	39.12	3.94	33.78	43
	Speed Other Far	37.32	9.53	23.05	58.31	42.59	9.06	30.95	50
	Average Speed Other	36.38	10.36	20.49	57.36	40.85	5.90	32.37	45.42
	Average Speed Near	35.88	10.66	19.20	55.65	38.08	5.02	30.57	40.81
	Average Speed Far	37.80	9.40	25.45	59.46	41.88	8.56	31.05	49.52
	Near to Far Speed Ratio	0.94	0.12	0.75	1.19	0.92	0.11	0.82	1.04
	Average Speed All	36.84	9.88	22.33	57.56	39.98	6.53	30.81	45.16
Gap	Gap MC Near	10.17	8.13	2.55	24.9	7.99	6.07	3.34	16.51
	Gap MC Far	10.16	11.48	2.94	37.28	13.35	13.32	4.18	33.01
	Average Gap MC	10.17	9.54	3.63	31.09	10.67	9.66	3.76	24.76
	Gap Other Near	8.56	7.90	2	24.27	7.57	7.30	2.22	18.03
	Gap Other Far	9.95	12.69	2.32	41.59	12.14	13.70	3.84	32.57
	Average Gap Other	9.25	9.96	2.71	31.45	9.85	10.45	3.03	25.3
	Average Gap Near	9.36	7.98	2.39	24.15	7.78	6.68	2.78	17.27
	Average Gap Far	10.06	12.07	2.63	39.44	12.75	13.50	4.01	32.79
	Near to Far Gap Ratio	1.24	0.67	0.49	2.61	0.68	0.15	0.53	0.88

S.D = Standard Deviation, Min = Minimum, Max = Maximum,
[a] For sites having single crash there is no variation in crash frequency, therefore, there is no need to calculate Mean, S.D, Min, Max.

the size of gap among vehicles moving in opposite direction increases the risk of crash. Although the mean volume on minor road on sites with single crashes was higher than the mean volume on minor road on sites with multiple crashes but the mean value of the average gap between vehicles that move in the near side direction was less on the later as compared to the former. This indicates that numbers of crashes are more dependent on the traffic characteristic of the major road as compared to the minor road.

3.1.2. Descriptive analysis of serious versus no serious conflicts

Similar to crash data, descriptive analysis of conflict data was also performed and presented in Table 3. The difference in mean road width between sites that had serious conflicts and no serious conflicts was prominent. No serious conflict was observed on narrower road while serious conflicts were observed on wider roads which indicated that intersections located on wider major roads are more prone to conflicts, therefore, have a higher risk of crash. These findings were identical to the ones presented by Ahmed et al. [27] which stated that “the risk of crash associated with unsignalized intersections increases with the increase in major road width”. This result is also conformal with the study conducted by Hamed et al. [28] in which the number of lanes in the major approach were shown to have a positive effect on the mean critical gap indicating that intersections with wider major road width require greater gap size to be accepted and hence are more prone to conflicts and crashes.

The near to far volume ratio for sites that have serious conflicts was found to be greater than one, while on sites where no serious conflicts was observed, the ratio was less than one. This shows that intersections that have a higher volume of vehicles moving in the near side direction are riskier than those which have less volume. Furthermore, the percentage of motorcycles moving in the far side direction as well as the total percentage of motorcycles was found to be higher on intersections that had no serious conflict as compared to the intersections that had serious conflicts. This indicates that higher percentage of motorcycles in the traffic mix decreases the risk of crash. However, the volume of minor road vehicles was found to be significantly less on sites that had no serious conflict as compared to sites that had serious conflict which expressed the ‘exposure dependency’ of the frequency of crash.

On sites that experienced no serious conflict, the mean values of the nine parameters of speed, which were: speed motorcycle near, speed motorcycle far, average speed motorcycle, speed other near, speed other far, average speed other, average speed near, average speed far, and average speed all; were found to be higher as compared to the sites that experienced serious conflicts. These results were contradictory with the results observed in crash analysis. Therefore, the sites with serious conflicts were explored further and it was found that maximum number of serious conflicts was observed on intersection that had the highest speed among all the intersections within the category. This shows that the chances of serious conflict increase with the increase in speed of vehicles. This result is supplemented by the study conducted by Spek et al. [29] which concluded that the probability of collision increases with the increase in major stream vehicles approach speed.

Analysis with respect to gap size revealed that the sites that experienced serious conflicts had smaller values of average gap or longitudinal distance between vehicles moving in the near side direction as compared to far side direction while the sites that experienced no seri-

Table 3
Descriptive statistics of sites with serious and no serious conflicts.

		Sites having Serious Conflicts				Sites having No Serious Conflicts			
		Mean	S.D	Min	Max	Mean	S.D	Min	Max
Number of Serious Conflicts		5.67	8.08	1	15	[a]	[a]	[a]	[a]
Road Width		12.6	3.73	8.3	15	8.53	2.15	7.1	11
Volume	Near to Far Volume Ratio	1.87	0.16	1.7	2.01	0.72	0.25	0.43	0.88
	Percent MC Far Side	27.54	3.61	23.65	30.79	52.57	14.34	38.11	66.79
	Total Percent MC	23.46	3.57	21.35	27.58	52.09	13.08	39.32	65.46
	Volume MC Near	575	338	185	772	474	186	285	656
	Volume MC Far	427	279	109	634	759	442	348	1226
	Total Volume MC	1002	615	294	1403	1232	547	633	1706
	Volume Other Near	2378	1617	527	3518	543	398	161	956
	Volume Other Far	1199	828	245	1734	803	546	173	1140
	Total Volume Others	3576	2434	772	5135	1346	910	334	2096
	Total Volume Near	2953	1952	712	4287	1017	583	446	1612
	Total Volume Far	1625	1101	354	2271	1562	933	521	2322
	Total Volume Major	4578	3049	1066	6538	2578	1397	967	3454
	Total Volume Minor	86	9	80	96	21	26	3	51
Speed	Speed MC Near	35.89	7.41	27.35	40.61	39.61	17.54	20.47	54.9
	Speed MC Far	38.96	7.37	31.14	45.78	41.92	16.86	27.86	60.61
	Average Speed MC	37.43	7.19	29.25	42.75	40.77	16.80	24.17	57.76
	Speed Other Near	36.25	3.98	33.78	40.84	40.11	19.90	17.93	56.4
	Speed Other Far	39.69	9.62	30.95	50	39.74	17.70	23.05	58.31
	Average Speed Other	37.97	6.72	32.37	45.42	39.93	18.51	20.49	57.36
	Average Speed Near	36.07	4.98	30.57	40.275	39.86	18.71	19.20	55.65
	Average Speed Far	39.33	8.43	31.05	47.89	40.83	17.23	25.46	59.46
	Near to Far Speed Ratio	0.93	0.08	0.84	0.98	0.96	0.22	0.75	1.19
	Average Speed All	37.70	6.65	30.81	44.08	40.35	17.63	22.33	57.56
Gap	Gap MC Near	7.68	7.68	2.55	16.51	14.93	8.45	7.33	24.02
	Gap MC Far	14.93	15.66	5.51	33.01	11.74	11.04	4.47	24.44
	Average Gap MC	11.31	11.67	4.03	24.76	13.33	9.50	6.82	24.23
	Gap Other Near	7.73	8.93	2.22	18.03	13.71	9.40	6.27	24.27
	Gap Other Far	13.92	16.16	4.32	32.57	11.06	10.47	4.75	23.15
	Average Gap Other	10.82	12.54	3.27	25.30	12.39	9.85	5.77	23.71
	Average Gap Near	7.70	8.30	2.39	17.27	14.32	8.90	6.80	24.15
	Average Gap Far	14.43	15.91	4.92	32.79	11.40	10.75	4.61	23.80
	Near to Far Gap Ratio	0.54	0.07	0.49	0.62	1.60	0.88	1.01	2.61

S.D = Standard Deviation, Min = Minimum, Max = Maximum,

[a] For sites having no serious conflicts, the number of serious conflicts will be zero; therefore, there is no need to calculate Mean, S.D, Min, Max.

ous conflict had greater values of average gap between vehicles moving in the near side direction as compared to far side direction. This result is quite similar to the result obtained in crash analysis, which showed that the variation in the size of gap among vehicles moving in opposite direction increases the risk of crash. Furthermore, the intersections that have smaller gap values of near side as compared to far side were found to be more hazardous than those that have greater gap values of near side as compared to far side.

3.1.3. Exploration of volume ratio and proportion of motorcycles in relation to crash frequency

Graphical analysis of the data revealed a relationship between crash frequency and two independent variables, which were 'Near to Far Volume Ratio' and 'Percentage Motorcycle Far Side'. Fig. 2, shows that multiple crashes were observed on sites where the Near to Far Volume Ratio was greater than one. It was also observed that the percentage of motorcycles in the traffic volume moving in the far side direction were comparatively less on sites where crash frequency was greater than one with respect to sites having only one crash. From these results it was inferred that there exists a relationship between the three variables. This led to the formulation of the hypothesis that the 'Chances of having multiple crashes is more on sites with less percentage of motorcycles in the far side direction given that the near to far volume ratio is greater than one'. Hence conditional probability was calculated.

Given the argument above the trend for number of sites which had percentages of motorcycles moving in the far side direction less than 31% and greater than 31% across various crash frequencies were observed as shown in Fig. 3(a). A constant decreasing trend was seen for the number of sites which possessed higher percentage of motorcycles in their traffic mix across crash frequencies. Contrary to it the numbers for the sites with lesser percentage of motorcycles in their traffic mix, decreased and then increased with the increase in crash frequency. This implicates that increase in the percentage of motorcycles in the traffic mix decreases the chances of crashes. Such finding is similar to the conclusions drawn by Harnen et al. [12] in which the volume of vehicles other than motorcycles were found to have the highest effect on the crash frequency of motorcycles at unsignalized intersections. Furthermore, among the sites used in the conflict study, none experienced a serious conflict which had higher percentage of motorcycles in their traffic mix, as shown in Fig. 3(c). Hence, intersections with higher percentage of motorcycles in their traffic mix will experience less severe crashes. In other words, sites with higher percentage of more robust vehicles such as buses and heavy goods vehicles are more prone to crashes of greater severity because a crash involving a car and a vulnerable road user, like pedal cycle, will not be as severe as a crash involving a car and a heavy goods vehicle [30].

Another trend to be observed was for the number of sites which had the 'near to far volume ratio' less than 1 and greater than 1 across various crash frequencies as shown in Fig. 3(b). Although in both cases; that is, for ratio less than 1 as well as greater than 1, the number of sites decreased with increasing crash frequency, but none of the sites which had ratio less than 1 experienced multiple crashes. Contrary to it the sites which had ratio greater than 1 did experience multiple crashes. Similar to the phenomenon observed for the variable of 'percentage of motorcycles in the far side direction', none of the sites used in the conflict study experienced a serious conflict which had 'near to far volume

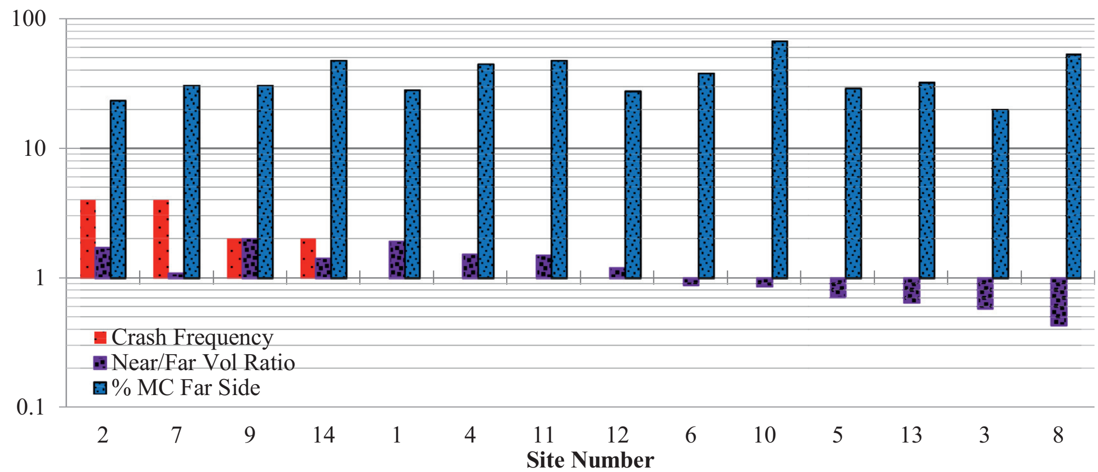

Fig. 2. Crash Frequency, Near to Far Volume Ratio and Percentage of Motorcycles in the far side direction.

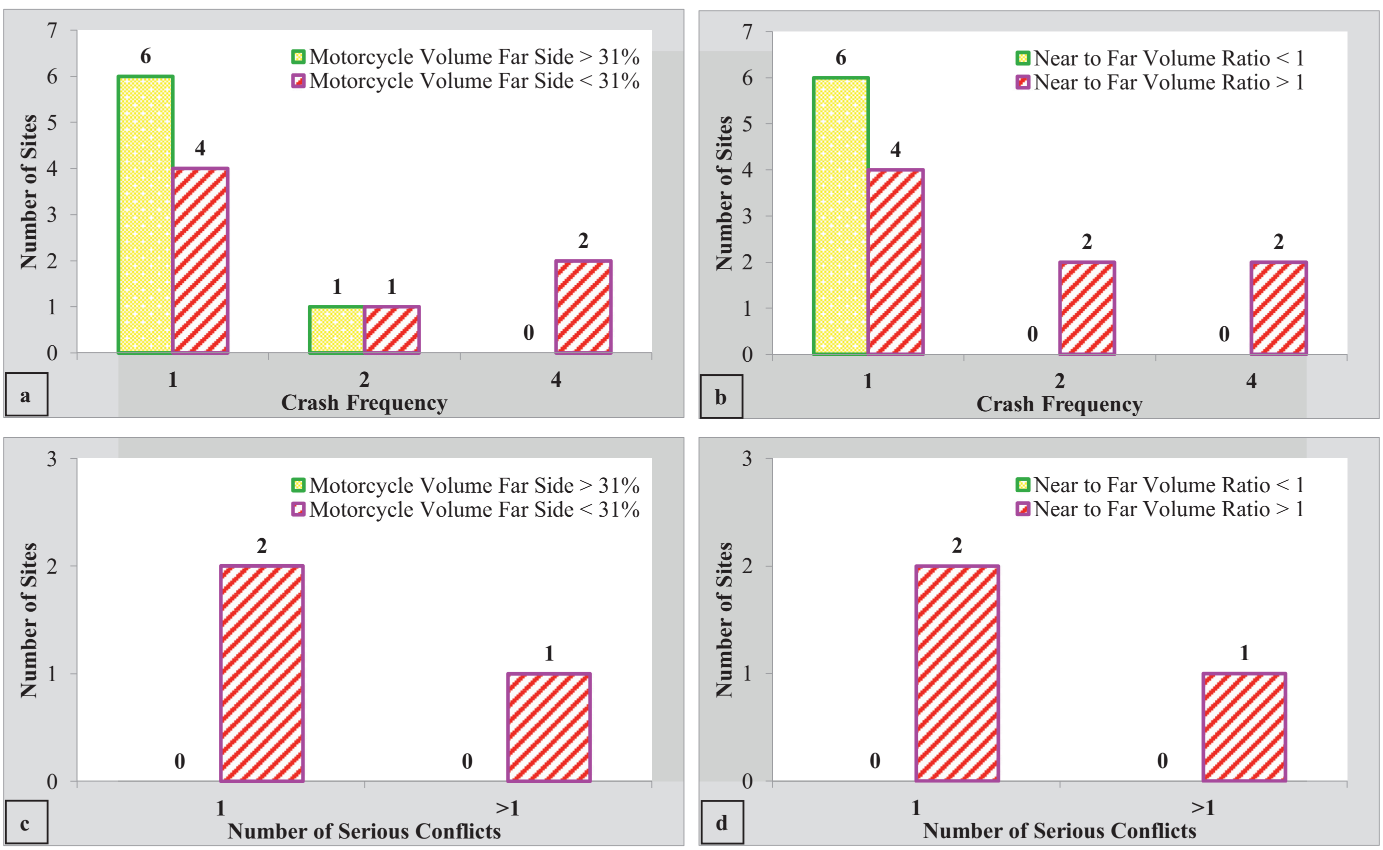

Fig. 3. (a) Number of sites across various crash frequencies and %Motorcycle in far side direction. (b) Number of sites across various crash frequencies and near to far volume ratios. (c) Number of sites across various conflict frequencies and %Motorcycle in far side direction. (d) Number of sites across various conflict frequencies and near to far volume ratios.

ratio' less than 1, as shown in Fig. 3(d). Since the 'near to far volume ratio' is a unique variable that has not been used before, therefore no literature was available which was related to it.

3.2. Conditional probability

In the analysis with respect to crashes 'Scenario 1' represents the situation where the chances of having a single crash is calculated given that the percentage of motorcycles moving in the far side direction increases provided that the near to far volume ratio is greater than one, and 'Scenario 2' represents the situation where the chances of having two crashes is calculated given that the percentage of motorcycles moving in the far side direction increases provided that the near to far volume ratio is greater than one. In the analysis with respect to conflicts 'Scenario 1' represents the situation where the chances of having a single serious conflict is calculated given that the percentage of motorcycles moving in the far side direction increases provided that the near to far volume ratio is greater than one, and 'Scenario 2' represents the situation where the chances of having more than one serious conflicts is calculated given that the percentage of motorcycles moving in the far side direction increases provided that the near to far volume ratio is greater than one. From Table 4 it is clearly evident that in the two scenarios with respect

Table 4
Results of the probability of crashes and probability of conflicts.

	Percentage of motorcycles in far side direction	Conditional Probability	%Difference
Conditional Probability of Crashes			
Scenario 1: The number of crashes equals 1, subject to	> 31%	0.375	25%
the condition that the Near to Far Volume Ratio remains	< 31%	0.625	
Scenario 2: The number of crashes equals 2, subject to	> 31%	0.50	25%
the condition that the Near to Far Volume Ratio remains	< 31%	0.75	
Conditional Probability of Conflicts			
Scenario 1: The number of conflicts equals 1, subject to	> 31%	0.67	33%
the condition that the Near to Far Volume Ratio remains	< 31%	1.0	
Scenario 2: The number of conflicts > 1, subject to the	> 31%	0.33	67%
condition that the Near to Far Volume Ratio remains > 1	< 31%	1.0	

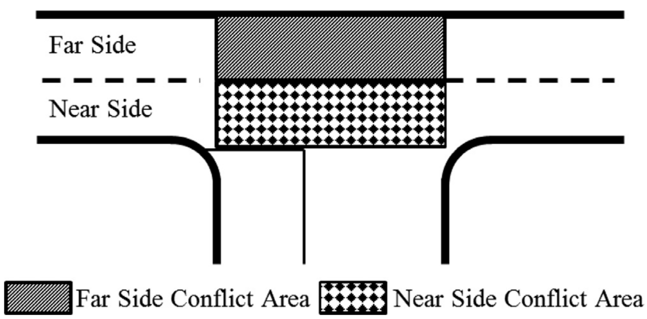

Fig. 4. Near/Far side conflict area.

to crashes, the probability of crash increases with the decrease in the percentage of motorcycles moving in the far side direction. Identical results were obtained for the analysis with respect to conflicts. The result is supported by the findings of Tiwari et al. [31] from which it can be inferred that in a heterogeneous traffic environment, such as India and Malaysia, Motorized Two Wheelers (MTW) are the less conflict causing road user group as compared to trucks, buses, minibuses, cars, vans, mini-vans, and jeeps. For signalized intersections, with heterogeneous traffic conditions, the increase in the proportion of MTWs has been reported to have an increasing effect on the crash frequency [32]. But for unsignalized intersections, the effect was found to be vice versa.

The results further strengthen the relationship, presented in the descriptive analysis, between crash frequency and the two other variables, which were ‘Near to Far Volume Ratio’ and ‘Percentage Motorcycle Far Side’. From the study it is contemplated that the more the difference in volume between vehicles moving in the opposite direction the more difficult it would be, for the minor driver, to find suitable gap. This increases the waiting time and encourages the minor road driver to take risk by selecting inappropriate gaps. The driver makes decision based on the gap available in the traffic stream moving in the far side direction assuming that he can clear the near side conflict area more quickly. As already discussed in the results of the conflict analysis, the sites that had smaller values of average gap or longitudinal distance between vehicles moving in the near side direction as compared to far side direction experienced serious conflicts while the sites that experienced no serious conflict had greater values of average gap between vehicles moving in the near side direction as compared to far side direction. Thus, the less importance given to the traffic moving in the near side direction resulted into crashes. Figure 4 shows the near/far side conflict area in a major/minor street setup.

It has been observed that when minor road driver tries to force merge into the major stream, the smaller sized major stream vehicles with greater maneuverability such as motorcycles can sway quickly from their path giving chance to minor stream vehicle to merge into the major stream without any collision. Thus, the proportion of larger vehicles, such as buses and trucks increase the injury risk. Such was reported by Wong et al. [33] in their study related to signalized intersections. They further argued that drivers of these commercial vehicles possess aggressive behavior, as reported by Pei et al. [34] also, and engage in dangerous acts like speeding and making hazardous maneuvers which increase the risk for other road users. The similar phenomenon was found to be true for unsignalized intersections, as the case in this study, where sites with higher percentage of larger automobiles, in comparison to motorcycles, experienced serious conflicts and more crashes. Therefore, the results conclude that traffic mix plays a major role in the number of crashes along with variation in directional traffic volume. The outcomes of this study extend the findings of Ahmed et al. [35] who observed that only the sites that had near to far volume ratio greater than one experienced multiple crashes, that is, intersections with more volume in the near side direction as compared to far side direction were more hazardous than the ones in which the difference in volume was vice versa.

4. Conclusion

Traffic mix and traffic volume both influence the crash frequency of a particular intersection. The effect of directional flow, in conjunction with the attachment of minor road with the major road, on the safety of unsignalized intersections has been argued in previous studies but the contribution of traffic mix in this context has not been established yet. The effort presented in this research attempts to highlight the relationship between traffic volume, traffic mix and number of crashes/conflicts and elaborates the underlying conditions which increase the probability of crashes at unsignalized intersections. Series of conditional probabilities were calculated for both crashes and conflicts, which utilized two different percentages of motorcycles in the traffic mix for the volume that moves in the far side direction of an intersection, subject to the condition that the near side to far side volume ratio remains greater than one.

The results have shown that the probabilities of single as well as multiple crashes increase with the decrease in the proportion of motorcycles in the traffic volume moving in the far side direction. Similarly, the probabilities of single as well as multiple conflicts increase with the decrease in the proportion of motorcycles in the traffic volume moving in the far side direction. Hence, it is established that a decrease in the percentage of motorcycles will increase the risk of crashes and conflicts subject to the condition that there exists a variation in the traffic flow that moves in the opposite direction with more volume in the near side as compared to the far side direction. It is recommended that unsignalized intersections located in areas of mixed landuse with high volume of commercial vehicles should be evaluated for their safety. Suitable measures can be taken to reduce the risk of crash at such sites like modification in their geometric design and improvement in their traffic control.

The strength of the model presented in this study is that it eliminates the requirement of long-term data recording of traffic volume. Such type of data is necessary for the estimation of Annual Average Daily Traffic (AADT) which is the most common parameter used in studies that involve crash modeling. Furthermore, use of AADT eliminates the effect of directional and temporal variation in traffic volume on crashes. Because of this, the analysis does not reflect the complete picture of the safety situation pertinent to each site. Such kind of investigation lacks explanation of the reasons behind the risk associated with the occurrence of crashes at a micro-level.

This research has introduced the 'near to far volume ratio' as an important variable which has a strong influence on the crash frequency of priority three-legged intersections. It is recommended that all such priority three-legged intersections, where the volume of traffic moving in the direction near to the minor road is greater than the volume moving in the opposite direction, should be evaluated for their safety. The method presented in this study simplifies the need to utilize several variables to explain the association of crashes to a particular site thus reducing the amount of data required to be collected for crash investigations at black spots. It is hoped that the framework described in this work will foster new approaches towards analyzing the risk of crashes at unsignalized intersections.

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships with any person or organization that may influence the work reported in this manuscript.

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Appendix A

Table A.1

Table A.1
Geometric and traffic characteristics of each site.

Site Number	Geometry	Traffic Control	Speed Limit	Total Volume[a]	% MC
1	Three-legged	SC	70 km/h	6538	21
2	Three-legged	SC	70 km/h	6131	21
3	Three-legged	SC	70 km/h	6580	23
4	Three-legged	SC	70 km/h	3288	39
5	Three-legged	SC	70 km/h	4252	28
6	Three-legged	SC	70 km/h	3454	39
7	Three-legged	SC	60 km/h	2787	33
8	Three-legged	SC	60 km/h	3314	51
9	Three-legged	SC	70 km/h	1066	28
10	Three-legged	SC	60 km/h	967	66
11	Three-legged	SC	50 km/h	868	46
12	Three-legged	SC	70 km/h	6565	35
13	Three-legged	SC	70 km/h	7148	27
14	Three-legged	SC	70 km/h	6644	40

SC: Stop Controlled
% MC: Percentage Motorcycle
[a] Three-hour traffic volume

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