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Technical Note

Predictive Model for Motorcycle Accidents at Three-Legged Priority Junctions

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In conjunction with a nationwide motorcycle safety program, the provision of exclusive motorcycle lanes has been implemented to overcome link-motorcycle accidents along trunk roads in Malaysia. However, not much work has been done to address accidents at junctions involving motorcycles. This article presents the development of predictive model for motorcycle accidents at three-legged major-minor priority junctions of urban roads in Malaysia. The generalized linear modeling technique was used to develop the model. The final model reveals that motorcycle accidents are proportional to the power of traffic flow. An increase in nonmotorcycle and motorcycle flows entering the junctions is associated with an increase in motorcycle accidents. Nonmotorcycle flow on major roads had the highest effect on the probability of motorcycle accidents. Approach speed, lane width, number of lanes, shoulder width, and land use were found to be significant in explaining motorcycle accidents at the three-legged major-minor priority junctions. These findings should enable traffic engineers to specifically design appropriate junction treatment criteria for nonexclusive motorcycle lane facilities.

Keywords Cross-Sectional Analysis; Generalized Linear Models; Junction Geometry; Junction Treatment Criteria; Motorcycle Accident Models; Motorcycle Accidents

Statistics reveal that junctions are accident-prone areas because a large proportion of accidents have been reported to occur at junctions (ITE, 2002; PDRM, 2002). Despite improved junction design and more sophisticated application of traffic engineering measures, the annual death toll due to traffic accidents has not changed substantially in more than 25 years (ITE, 2002). Based on the present accident scenario, there is an urgent need to specially design the strategic plans and programs for reducing traffic accidents at junctions (ITE, 2000; NCHRP, 2000).

Previous studies on traffic accidents at junctions or at links with junctions have been mainly concerned with all vehicle accidents (Affum & Taylor, 1996; Bauer & Harwood, 2000; Mountain et al., 1998; Rodriguez & Sayed, 1999; Saied & Said, 2001; Taylor et al., 2002; Vogt, 1999; Vogt & Bared, 1998; Wang & Ieda, 1997). However, there is evidence that motorcycle accidents at junctions are also significant (DETR, 1999; FORS, 1999; PDRM, 2002; Radin Umar, 1996; Summersgill, 1991), and studies have highlighted that the chances of fatality and injury to motorcyclists are much higher than to passenger car occupants (Cesari, 1999; DETR, 1999; NHTSA, 2001; PDRM, 2002; Radin Umar, 1996). Therefore, more extensive research in this area, especially on motorcycle accidents at junctions, is strongly justified.

Early models of traffic accidents were developed using classical linear regression, based on the assumption of normal error structure with a constant variance. However, the use of generalized linear models (GLMs) (McCullagh & Nelder, 1989) with Poisson or negative binomial error structure has been increasingly accepted as more appropriate than the classical linear model. The use of GLMs for the development of predictive models for traffic accidents, utilizing either the cross-sectional or the time series approach, has been reported by some researchers in earlier studies (Bauer & Harwood, 2000; Mountain et al., 1996,

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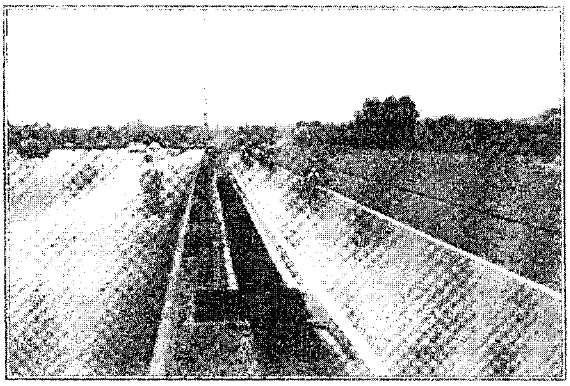

Figure 1 A typical view of an exclusive motorcycle lane in Malaysia.

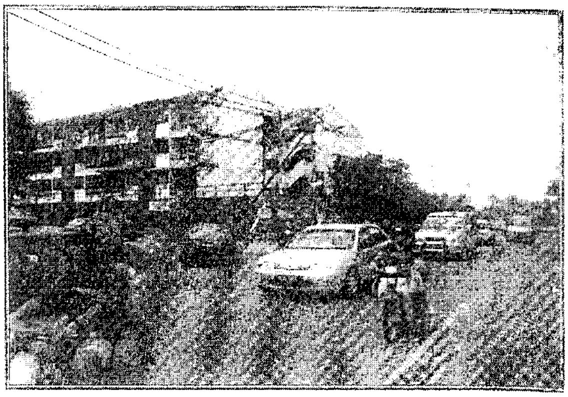

Figure 2 A typical selected junction in Malaysia.

1998; Radin Umar, 1996; Radin Umar et al., 1995, 2000; Saied & Said, 2001; Taylor et al., 2002; Vogt, 1999; Vogt & Bared, 1998).

Since the introduction of the world's first exclusive motorcycle lane in Malaysia (Figure 1), which was aimed at addressing link-motorcycle accidents along trunk roads, numerous studies have been carried out to investigate the effect of such lanes on motorcycle accidents along the route (Radin Umar, 1996; Radin Umar et al., 1995, 2000). However, not much research has been done to address motorcycle accident problems at junctions. Thus, it is necessary to carry out in-depth investigations on factors contributing to motorcycle accidents at junctions. Apart from addressing the exclusive lane criteria, such research would enable the design of appropriate junction treatment criteria specifically for exclusive and nonexclusive motorcycle lane facilities. As an initial effort, a predictive model for motorcycle accidents at three-legged major-minor priority junctions has been developed. This article presents the development of such model for urban roads in Malaysia. The GLM approach was used in this study because as its superiority in traffic accident modeling studies has been well established. A log-linear cross-sectional model with Poisson and negative binomial errors (NAG, 1996) was incorporated to refine this model. The estimation of the parameters and tests of their significance were carried out using the statistical software GLIM 4 (NAG, 1994), specially designed for fitting generalized linear models.

METHOD

In this study, a total of 36 three-legged major-minor priority junctions located at urban roads in four districts of the state of Selangor, Malaysia, were randomly selected. Figure 2 shows a typical junction selected in this study. A 4-year period (1997–2000) of motorcycle accident data on the selected junctions was used in this study. The accident data were procured from the police accident recording form POL 27 (Pin 1/91). This form is specially designed for easy completion (Radin Umar et al., 1993) and is fully compatible with the TRL's Microcomputer Accident Analysis Package (MAAP: Hills & Baguley, 1993). It should be mentioned that only fatal and hospitalized accident data were available in the MAAP files for the study period. As such, additional data was extracted from the Computerized Accident Recording System (CARS) database for slight injury accidents. The MAAP database is available at the Road Safety Research Center, Universiti Putra Malaysia, while the CARS database is located at the Royal Malaysian Police Headquarters. Different severity levels of motorcycle accidents were considered in this study. They were classified as fatal, hospitalized, and slight injury accidents. Junction accidents were defined as any accident occurring within a 50 m distance from the corresponding stop line of the junction. Four-year injury motorcycle accident frequencies at the selected junctions are presented in Figure 3 where the ratio of Fatal:Serious:Slight Injury is about 1:2.4:8.

Traffic flow data used in this study were based on the estimated annual average daily traffic (AADT) for each selected junction. Records of hourly traffic volume (disaggregated by nonmotorcycles and motorcycles) counted on each approach of the junction were converted to the AADT using hourly, daily, and monthly factors. Such factors were developed using the 24-h permanent traffic count stations and traffic census data available at the Highway Planning Unit, Ministry of Works Malaysia (HPU, 2001a,b). These factors were based on the method proposed by McShane et al. (1998). The AADTs were expressed in terms of number of nonmotorcycles per day (nmpd) and motorcycles per day (mpd). The AADT for nmpd on major roads ranged from 14,449 to 47,834 and on minor roads from 3,812 to 19,120, while for mpd it ranged from 4,252 to 19,646 on major roads and from 1,388 to 3,869 on minor roads. The term *nonmotorcycle* refers to all types of motorized vehicles excluding motorcycles.

The junction geometry (lane width, number of lanes, and shoulder width), traffic speed, pedestrian flow, and land use at the selected junctions were also considered in the study. The junctions were selected based on the following conditions: There had been only marginal or insignificant change in land use, no major modifications or upgrading, no raised islands, and an equal

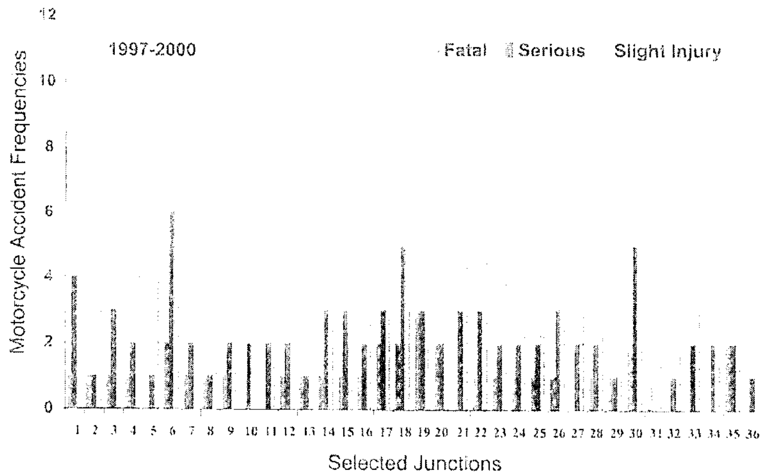

Figure 3 Motorcycle accident frequencies at the selected junctions.

number of lanes on the corresponding major and minor road approaches. The junction geometry, approach speed, and pedestrian flow were measured on site because such data was not available in the database. The data were collected on site using similar assumptions made in an earlier study (Golias, 1997). The 85th percentile speed was used to represent approach speed at each junction. Such an approach speed was also considered in an earlier study on traffic accidents at roundabouts (Arndt & Troutbeck, 1998). Approach speeds were measured at a distance of 50 m upstream from the corresponding stop lines of the junctions. Pedestrian flow at each junction was defined as the total number of pedestrian crossings per hour recorded on major and minor roads. Lane width on major and minor roads ranged from 3.3 to 4.2 m and from 3.4 to 4.0 m, respectively. The number of lanes for respective major and minor road approaches ranged fr 1 to 3 lanes. Meanwhile, the average shoulder width on major and minor roads ranged from 0.0 to 1.2 m. The approach speed ranged from 50.0 to 66.5 km/h while the number of pedestrian crossings ranged from 0 to 109 pedestrian/hour.

Meanwhile, land use at each selected junction was also observed during site data collection. Land use was classified into two categories: commercial and noncommercial areas. Commercial areas were identified as those areas with concentrations of offices, shops, railway stations, and bus stations. The noncommercial areas were identified as being residential or unused. Of the 36 junctions, 21 junctions were located in commercial areas and 15 in noncommercial areas. It should be noted that junctions located in commercial areas with access roads within a distance of 50 m from the junction stop lines were excluded in this study.

Before undertaking the statistical modeling, some major features for the modeling process had to be prepared: The theoretical model had to be formulated, the error structure and link function had to be specified, the variables of the model had to be identified, and the goodness-of-fit and significant tests had to be defined. OECD (1997) has suggested that the choice of regressors should primarily be based on the theory used, the questions to be answered, and professional knowledge rather than the multiple correlation and curve-fitting ambition. Taking this suggestion into account, the variables of the model were defined.

In this study, the response variable was the number of motorcycle accidents and the explanatory variables were traffic flows (disaggregated by nonmotorcycle and motorcycle), pedestrian flow, traffic speed, lane width, number of lanes, shoulder width, and land use. The continuous variables were identified as traffic flow, pedestrian flow, traffic speed, lane width, and number of lanes, while the categorical variables were shoulder width (SHDW) with 3 factor levels and land use category (LU) with 2 factor levels. The data on junction geometry showed that the number of lanes for all minor road approaches was equal to one (LNn = 1). Therefore, this variable was excluded in the analysis.

Taking into consideration the earlier studies on junction accident modeling, the theoretical model which contains all the terms used in this study is as follows:

$$\mathrm{MCA} = \mathrm{k}\ \mathrm{QNMm}^{\alpha_1}\ \mathrm{QNMn}^{\alpha_2}\ \mathrm{QMm}^{\alpha_3}\ \mathrm{QMn}^{\alpha_4}\ \mathrm{QPED}^{\alpha_5}$$
$$\mathrm{EXP}^{(\beta_1 \mathrm{SPEED} + \beta_2 \mathrm{LWm} + \beta_3 \mathrm{LWn} + \beta_4 \mathrm{LNm} + \beta_5 \mathrm{SHDW} + \beta_6 \mathrm{LU} + e)} \quad (1)$$

where MCA is motorcycle accidents (response variable), while the explanatory variables and the descriptions are presented in Table I. The k, $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5$, and β_6 are the coefficients to be estimated and the e term is the error representing the residual difference between actual and predicted models. Using a logarithmic transformation, the log-linear version of the model is

$$\mathrm{Ln(MCA)} = \mathrm{Ln(k)} + \alpha_1 \mathrm{Ln(QNMm)} + \alpha_2 \mathrm{Ln(QNMn)}$$
$$+ \alpha_3 \mathrm{Ln(QMm)} + \alpha_4 \mathrm{Ln(QMn)} + \alpha_5 \mathrm{Ln(QPED)}$$

Table 1 Explanatory variables: Descriptions, factor levels, and coding system in GLIM

Explanatory variables	Descriptions	Factor levels	Coding systems
QNMm	Nonmotorcycle flow on major road		QNMm (nonmotorcycles/day)
QNMn	Nonmotorcycle flow on minor road		QNMn (nonmotorcycles/day)
QMm	Motorcycle flow on major road		QMm (motorcycles/day)
QMn	Motorcycle flow on minor road		QMn (motorcycles/day)
QPED	Pedestrian flow on major and minor roads		QPED (pedestrians/hour)
SPEED	Approach speed on major and minor roads		SPEED (km/hour)
LWm	Average lane width on major road		LWm (m)
LWn	Average lane width on minor road		LWn (m)
LNm	Number of lanes on major road		LNm (lanes/traffic direction)
LNn	Number of lanes on minor road		LNn (lanes/traffic direction)
SHDW	Average shoulder width on major and minor roads	3	(1) SHDW = 0.00 m (2) 0.00 < SHDW < 1.00 m (3) SHDW ≥ 1.00 m
LU	Land use category	2	(1) Noncommercial area (2) Commercial area

$$+ \beta_1(\text{SPEED}) + \beta_2(\text{LWm}) + \beta_3(\text{LWn})$$

$$+ \beta_4(\text{LNm}) + \beta_5(\text{SHDW}) + \beta_6(\text{LU}) + e \qquad (2)$$

The total 4-year accident frequencies were used to fit the models. However, by introducing an offset variable (the term log) in the fitting process, the final model would estimate the number of accidents per year. This approach had been used in an earlier study on traffic accidents at junctions (Mountain et al., 1998).

Earlier studies on junction accidents (Mountain et al., 1998; Rodriguez & Sayed, 1999; Saied & Said, 2001; Vogt, 1999; Vogt & Bared, 1998) or on link accidents (Mountain et al., 1996; Radin Umar, 1996; Radin Umar et al., 1995, 2000; Taylor et al., 2002) used Poisson and negative binomial models to describe the distribution of accident occurrences. Maycock and Hall (1984) reported that the negative binomial analysis did not show any significantly different results compared to the Poisson analysis. Meanwhile, Miaou (1994) reported that the Poisson and negative binomial models had their uses, with negative binomial to be preferred if the data were sufficiently overdispersed. Bauer and Harwood (2000) used the Poisson, log-normal, and negative binomial distributions for modeling accidents at junctions. The general shape of accident frequency distribution was visually assessed by plotting the data of accident frequency for each category of junctions considered.

On the basis of these earlier studies, the model (Poisson or negative binomial) used in this study was based on the goodness-of-fit test carried out on the observed accident frequencies. Deviance was used as a measure of goodness-of-fit of the models (NAG, 1994, 1996). The minimum deviance generated in the fitting process was considered, as the observed frequencies were the closest fit to the theoretical frequencies being analyzed. In addition, a hypothesis test at the 5% significance level ($p < .05$) was carried out in selecting the model.

In this study, the quasi-likelihood approach (McCullagh & Nelder, 1989) was used to overcome the dispersion problem. This approach had been usefully employed in earlier studies on motorcycle accidents (Radin Umar, 1996; Radin Umar et al., 1995, 2000). The dispersion parameter was estimated from the mean deviance (scaled deviance over its degrees of freedom). This may form a model with scaled deviance equal to its degrees of freedom. The final model was based on the goodness-of-fit and the significance test carried out on the models, such as the change in scaled deviance from adding or removing the terms, the ratio of scaled deviance to its degrees of freedom (mean deviance), and t statistics of the parameter estimates significant at the 5% level.

Multivariate analysis was employed in this study. Such analysis allows for assessment of the variable(s) with the biggest impact on the probability of motorcycle accidents. Univariate analysis was also employed in this study (outside of this article) to obtain a complete picture of the effect of all explanatory variables on motorcycle accidents. It should be noted that only those variables found significant at the 5% level in univariate analysis were included in the multivariate analysis.

RESULTS

The goodness-of-fit test carried out on the Poisson and negative binomial models revealed that the Poisson model had a slight edge over the negative binomial in explaining the variation of accident occurrences. Deviance (D) for the Poisson model was 9.09 with 12 *df*, while the deviance (D) for the negative binomial model was 9.11 with 11 *df*. The hypotheses test also confirmed that the Poisson model was statistically significant ($p < .05$) in representing the variation of accidents under consideration. Since the Poisson model was used and a log-linear cross-sectional model was employed, the link function therefore would be specified as the log (NAG, 1994).

The preliminary analysis (univariate) found that the term QPED was not significant at the 5% level. This term therefore was excluded from any further analysis. The multivariate

Table II Multivariate analysis of the terms

Explanatory variable	Coefficient	SE	*df*	Scaled deviance	*z*-Value	Significant at .05	Mean deviance
Constant	−5.24100	0.38400	35	57070.0	13.65	Yes	1631.00
QNMm	0.21880	0.02350	34	2509.0	9.30	Yes	73.80
QNMn	0.06650	0.01410	33	1501.0	4.72	Yes	45.50
QMm	0.13200	0.01220	32	838.0	10.86	Yes	26.19
QMn	0.18080	0.03580	31	195.7	5.05	Yes	6.31
SPEED	0.02279	0.00218	30	95.9	10.43	Yes	3.20
LWm	−0.09690	0.01900	29	62.3	5.10	Yes	2.15
LWn	−0.07060	0.02830	28	49.0	−2.50	Yes	1.75
LNm	0.00738	0.00280	27	42.8	2.63	Yes	1.59
SHDW (2)	−0.00903	0.00403	25	29.8	2.24	Yes	1.19
SHDW (3)	−0.02099	0.00605	25	29.8	3.47	Yes	1.19
LU (2)	0.00755	0.00313	24	24.0	2.41	Yes	1.00

Coefficients for factors (2) and (3) are differences compared with the reference level (1).

lysis of the terms (Table II) shows that all explanatory variables were significant at the 5% level. The scaled deviance was equal to its degrees of freedom, as the quasi-likelihood approach had been introduced in the fitting process. The scaled deviance changed from 57,070.0 to 24.0 with a loss of 11 *df*. The mean deviance changed from 1,631.0 to 1.0.

Based on the multivariate analysis, the final model is

$$\mathrm{MCA} = 0.0059294\ \mathrm{QNMm}^{0.2188}\ \mathrm{QNMn}^{0.0665}\ \mathrm{QMm}^{0.132}\ \mathrm{QMn}^{0.1808}\ \mathrm{EXP}^{0.02279\,\mathrm{SPEED} - 0.0969\,\mathrm{LWm} - 0.0706\,\mathrm{LWn} + 0.00738\,\mathrm{LNm} + \beta_5\,\mathrm{SHDW} + \beta_6\,\mathrm{LU}} \quad (3)$$

where MCA is motorcycle accidents per year; $\beta_5 = 0.0$, 0.00903 and 0.02099 for SHDW = 1, 2, and 3, respectively; $\beta_6 = 0.0$ and 0.00755 for LU = 1 and 2, respectively.

PLICATION OF THE MODEL

In order to determine an appropriate intervention level for junction treatment, friendly use software (Figure 4) was specifically designed to estimate motorcycle accidents at junctions, expressed in personal injury accidents (PIAs) per year. The PIA for this example was 2.278. By setting an acceptable PIA limit, appropriate design parameters for the junction could be specified. This would allow room for engineers to decide appropriate design parameters for the junctions.

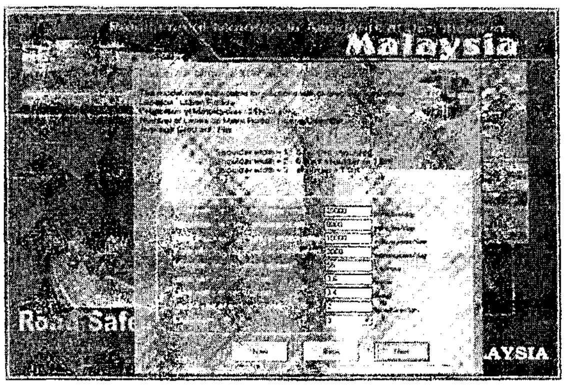

Figure 4 Data example.

DISCUSSION AND CONCLUSION

The present model suggests that traffic flow is significant in explaining motorcycle accidents at three-legged major-minor priority junctions. The number of motorcycle accidents is proportional to the power of traffic flow entering the junction. The estimates of QNMm, QNMn, QMm, and QMn indicate that an increase in nonmotorcycle and motorcycle flows on major and minor road approaches is associated with an increase in motorcycle accidents. For instance, doubling nonmotorcycles on a major road is expected to increase motorcycle accidents by about 16%, while doubling nonmotorcycles on both major and minor roads is expected to increase motorcycle accidents by about 21%. Doubling motorcycles on both major and minor roads is expected to increase motorcycle accidents by approximately 23%. If all traffic entering the junction were doubled, an increase of 44% in motorcycle accidents would result. It also was found that nonmotorcycle flow on a major road (QNMm) had the greatest effect on the probability of motorcycle accidents. It therefore is suggested that motorcyclists, on both major and minor roads, entering and leaving the junctions should pay attention to nonmotorcycle flow on a major road.

The model also reveals that approach speed and junction geometry (lane width, number of lanes, and shoulder width) are significant in describing motorcycle accidents. The estimate of SPEED explains that an increase in approach speed is associated with an increase in motorcycle accidents. For instance, an increase in approach speed of 10 km/h is expected to increase motorcycle accidents by about 26%.

The estimates of LWm and LWn imply that a wider lane is associated with a reduction in motorcycle accidents. For instance, widening lane on major and minor roads by 0.50 m is expected to reduce motorcycle accidents by about 5% and 3.5%, respectively.

Meanwhile, the estimate of LNm indicates that an increase in number of lanes on a major road is associated with a reduction in motorcycle accidents. However, the effect of this variable on motorcycle accidents is marginal (0.74%). The 0.74% reduction in motorcycle accidents is probably due to the presence of the exclusive turning lanes on a major road, as 24 of the 36 junctions were furnished with exclusive turning lanes on each major road. The presence of such lanes probably reduced rear-end accidents involving motorcycles.

The estimates of SHDW indicate that wider shoulders are associated with a reduction in motorcycle accidents. For instance, motorcycle accidents at junctions without shoulders were about 2.1% higher than those at junctions with shoulders wider than 1.00 m. Motorcycle accidents at junctions without shoulders were about 0.9% higher than those at junctions with shoulder widths of between 0.00 m and ≤ 1.00 m. The finding seems plausible since motorcyclists utilize available shoulders as a travel path when approaching the junction. This is common in countries with a high population of motorcycles such as Malaysia. In this situation, the rates of rear-end or sideswipe accident types between motorcycles on the shoulder and other vehicles on the way traveled are probably reduced.

The model reveals that land use is significant in explaining motorcycle accidents. The estimate of LU indicates that increases in activities in land use at junctions are associated with an increase in motorcycle accidents. However, the difference in expected motorcycle accidents between these two land use categories was marginal (0.76%). This is probably due to the absence of access roads within 50 m of the junction stop lines for selected junctions located within commercial areas. As such the number of conflicts between vehicles entering or leaving the junction and vehicles turning in or out to the land use may have been low, thus reducing accidents.

Based on the findings, the following conclusions may be drawn.

1. Traffic flow is significant in explaining motorcycle accidents at three-legged major-minor priority junctions. The number of motorcycle accidents is proportional to the power of traffic flow entering into the junction. An increase in motorcycle and nonmotorcycle flows entering the junction is associated with an increase in motorcycle accidents. Nonmotorcycle flow on major road had the highest effect on a the probability of motorcycle accidents.
2. Approach speed on major and minor road approaches is significant in explaining motorcycle accidents. An increase in approach speed is associated with an increase in motorcycle accidents.
3. Junction geometry (lane width, number of lanes, and shoulder width) is significant in explaining motorcycle accidents. Wider lanes, a greater number of lanes, and wider shoulders are associated with a reduction in motorcycle accidents.
4. Land use at junctions is found to be significant in explaining motorcycle accidents. Motorcycle accidents at junctions located within commercial areas are higher than those located within noncommercial areas.

The prediction model has been developed for motorcycle accidents at three-legged major-minor priority junctions on urban roads in Malaysia. Based on the model developed in this study, appropriate design parameters for the junctions could be determined for a given cut-off level of motorcycle accidents. The decision whether to allow motorcycles to pass through a junction without treatment or the need for special end treatment to minimize motorcycle conflicts at the junction (Shahrom, 2003) could be objectively carried out based on this model. However, this model might be valid for only a typical mixed traffic environment in developing countries like Malaysia, where the proportion of motorcycles constitutes 25% to 30% of all vehicles using three-legged priority junctions.

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