EFFECT OF TRAFFIC FLOW AND SHOULDER WIDTH ON MOTORCYCLE ACCIDENTS AT NON-SIGNALIZED INTERSECTIONS

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ABSTRACT

The study is aimed to find the effect of traffic flow and shoulder width on motorcycle accidents at non-signalized intersections. Such figures were established based on the accidents prediction model developed in this study. The model containing traffic flow and shoulder width variables was developed using Generalized Linear Modeling approach with quasi likelihood technique. In addition, the study also attempts to find the traffic flow criteria over which accident countermeasures should be applied. The traffic flow criteria were established based on the relationship of the variables included in the model. The final model revealed that an increase in traffic flow (both on major and minor roads) entering the intersection is associated with an increase in motorcycle accidents. Shoulder width was found to be significant in describing motorcycle accidents at non-signalized intersections. These findings should enable engineers to draw up appropriate intersection treatment criteria specifically designed for motorcycle lane facilities.

Key words: motorcycle accidents, non-signalized intersections, generalized linear model, traffic flow criteria

1. INTRODUCTION

Statistics reveal that intersections are accident-prone areas because a large proportion of accidents have been reported to occur at intersections [1]. Despite improved intersection 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, [1]. Based on the present accident scenario, there is an urgent need to specially design the strategic plans and programs for reducing traffic accidents at intersections [2], [3].

Many studies in traffic accidents at intersections have revealed that traffic flow is an important variable in affecting traffic accidents. A study on traffic accidents at intersections carried out by Mountain et al. [4] confirmed that doubling major road flow has increased accidents by 46% for all type of intersections, and doubling minor road flow has increased accidents by some 13% at non-signalized intersections. Meanwhile, doubling traffic flow on both major road and minor road has increased accidents by about 65% at non-signalized intersections and by about 92% at signalized intersections. Another study on accidents at intersections carried out by Rodriguez and Sayed [5] pointed out that doubling major road and minor road flows on the three-legged non-signalized intersections has increased accidents by about 37% and 49%, respectively. A similar figure was affirmed by other researchers in their studies on accidents at intersections [6], [7], [8] found that the use of continuous paved shoulders at three-legged non-signalized intersection has reduced the number of overall conflicts among vehicles from 34 to 10 (p<0.05). This reduction will most likely mitigate the number of accidents at three-legged non-signalized intersections. The safety benefits to motorcyclists from the availability of shoulders at intersections seem to be important to deeply analyze in future traffic accidents studies. Bauer and Harwood [8] also confirmed that an increase of outside shoulder width on major road was associated with a reduction in traffic accidents. Furthermore, an increase of 1-foot (about 0.30 m) in shoulder width reduced traffic accidents by about 1.7% and 2% at rural three-legged stop controlled and urban four-legged stop controlled intersections, respectively.

Since the introduction of the world’s first exclusive motorcycle lane in Malaysia, 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 [9], [10], [11]. However, not much research has been done to address motorcycle accident problems at intersections. Thus, it is necessary to carry out in-depth investigations on factors contributing to motorcycle accidents at intersections. Apart from addressing the exclusive lane criteria, such research should enable engineers to draw up the design of appropriate intersection treatment criteria specifically for exclusive and nonexclusive motorcycle lane facilities.

As an extension to our earlier analysis [12], [13], [14], [15], [16], this study is aimed to find the effect of traffic flow and shoulder width on motorcycle accidents at non-signalized intersections. To find such effects the prediction model for motorcycle accidents at non-signalized intersections was developed in this study. The Generalized Linear Modeling (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 [17] was incorporated to refine the model. The estimation of the parameters and tests of their significance were carried out using the statistical software GLIM 4 [2], that specially designed for fitting generalized linear models. In addition, the model developed in this study will be used further to establish major road and minor road flows criteria for intersection treatment. This can be done by using the design curves relating major- and minor-road flows and shoulder widths developed based on the Model.
2. METHODS

The Data

In this study, a total of 53 intersections on urban roads in four districts of the state of Selangor, Malaysia were randomly selected. The selection of intersections was based on the criteria that the intersections had only marginal land use changes; had not undergone major modifications or upgrading; there was an equal number of lanes on the corresponding major- and minor-road approaches. Intersections located within commercial areas with access roads within 50-m distance from the intersection stop lines were excluded from this study. Only those intersections with a history of Personal Injury Accident (PIA) statistics were included in this analysis. This is because of the reliability of data and higher weightage given to PIA cases compared to damage-only accidents. In the present study, intersection accidents involving motorcycles were defined as any motorcycle accident occurring within a 50-m distance from the corresponding stop line of the intersection.

For the selected intersections, data on motorcycle accidents, traffic flow, pedestrian flow, traffic speed, intersection geometry, number of intersecting legs and land use were assembled and used in this study. Motorcycle accident data over a 4-year period (1997-2000) were collected from the archives of the police accident recording forms, POL 27 (Pin 1/91). This form is designed for easy completion [19] and fully compatible with the TRL’s Microcomputer Accident Analysis Package, the MAAP [20]. Data were extracted from two complementary databases that are based on the POL 27 recording forms: (a) the Microcomputer Accident Analysis Package (MAAP-5) database for fatal and hospitalized accidents, and (b) the Computerized Accident Recording System (CARS-2000) database for slight injury accidents. The MAAP database is located at the Road Safety Research Center, Universiti Putra Malaysia, while the CARS-2000 database is located at the Royal Malaysian Police Headquarters.

Traffic flow data, as defined by Annual Average Daily Traffic (AADT), consists of total traffic entering the intersection through the major- and minor-road approaches. Records of hourly traffic flow were then converted to AADT by using hourly, daily and monthly factors. These factors were estimated using the 24-hour permanent traffic count station and traffic census data available at the Highway Planning Unit, Ministry of Works Malaysia [21], [22]. Established techniques [23] commonly used to estimate the factors and the AADT were employed in this study. Meanwhile, data on shoulder width at each selected intersection were observed and recorded during site data collection. Of the 53 intersections, 36 were three-legged while 17 were four-legged intersections.

The Model

Prior to carrying out the statistical model, some preliminary work has to be done to facilitate the model process. This included formulating the theoretical models, specifying the error structure and link function, identifying the model variables, and defining the goodness-of-fit and significance tests.

Using our earlier analysis of motorcycle accidents at intersections [12], [13], [14], [15], [16] and studies of traffic accidents at intersections [24], [6], [7], [8], [26], the model structure and the variables included were defined. The response variable was motorcycle accidents, while the explanatory variables were traffic flow and shoulder width. Both traffic flow and shoulder width were continuous variables.

Taking the earlier studies on intersection accident model into consideration, the theoretical models containing all terms used in this study were formulated as follows:

\[ \text{MCA} = k \text{Qmajor}^{\delta_1} \text{Qminor}^{\delta_2} \exp(\lambda \text{SHD} + e) \]

where MCA is motorcycle accidents per year. Descriptions of the explanatory variables are presented in Table 1. The k, \(\delta_1\), \(\delta_2\) and \(\lambda\) are the parameters to be estimated and the (e) term is the error representing the residual difference between actual and predicted models.

<table>
<thead>
<tr>
<th>Explanatory Variables</th>
<th>Description</th>
<th>Coding Systems in GLIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qmajor</td>
<td>Traffic flow on major road (vehicles/day)</td>
<td>Qmajor</td>
</tr>
<tr>
<td>Qminor</td>
<td>Traffic flow on minor road (vehicles/day)</td>
<td>Qminor</td>
</tr>
<tr>
<td>SHD</td>
<td>Average shoulder width on major and minor roads (m)</td>
<td>SHD</td>
</tr>
</tbody>
</table>

Using a logarithmic transformation, the log-linear version of the model is:

\[ \ln(\text{MCA}) = \ln(k) + \delta_1 \ln(\text{Qmajor}) + \delta_2 \ln(\text{Qminor}) + \lambda \text{SHD} + e \]

To allow direct interpretation of the parameter estimates produced by GLIM 4, the flow functions of the equation need to be transformed using a natural logarithmic (Ln), while the others do not. It should be noted that the total four-year accident frequencies were used to fit the models. However, by introducing an offset variable in the fitting process, the final model would be able to estimate the number of accidents per year. This approach has also been implemented in earlier studies on traffic accidents at intersections [4] and motorcycle accidents at intersections [12], [13], [14], [15], [16].
The model was based on the Poisson error structure and used the quasi-likelihood approach [26] to overcome the dispersion problem. A log-linear cross-sectional model was employed with the link function specified as the log [18]. This approach has been used in earlier studies on motorcycle accidents on highway links [10], [27], [11] and in our earlier analysis of motorcycle accidents at intersections [12], [13], [14], [15], [16].

Using the quasi-likelihood approach, the dispersion parameter was estimated from the mean deviance (scaled deviance over its degrees of freedom). This may result in a model where the scaled deviance is equal to its degrees of freedom. The final model was based on the goodness-of-fit and significance tests 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 the 5% significance level of t-statistics of the parameter estimates. The multivariate analysis was carried out in this study. Such analysis was employed to assess which of the variable(s) had the most effect on the probability of motorcycle accidents.

3. RESULTS AND DISCUSSION

The Prediction Model

Table 2 presents the results of the multivariate analysis of the Model. All terms were found to be significant at the 5% level. The scaled deviance was equal to its degrees of freedom, because the quasi-likelihood approach had also been introduced in the fitting process. The scaled deviance changed from 3112.0 to 49.0 with a loss of 3 degrees of freedom and the mean deviance changed from 59.8 to 1.0.

The final model developed in this study was:

$$\text{MCA} = 0.0006039 \times Q_{\text{major}}^{0.5369} \times Q_{\text{minor}}^{0.2869} \times \exp^{0.0864 \times \text{SHD}}$$

where MCA is motorcycle accidents per year. Meanwhile, Figure 1 presents the actual and predicted motorcycle accidents.

![Fig. 1. Actual and Predicted Motorcycle Accidents](image)

The model results verify the contribution of traffic flow, both on major roads (Q major) and minor roads (Q minor), to motorcycle accidents. The estimates of the variables show that an increase in traffic flow on major and minor roads is associated with a greater number of motorcycle accidents. For instance, an increase in Q major by 40% is associated with an increase in motorcycle accidents by about 20%. The model also reveals that an increase in shoulder width (SHD) is associated with a reduction in motorcycle accidents. For example, widening the shoulder by 1.0 meters is expected to reduce the number of motorcycle accidents by 9%.

Establishing Traffic Flow Criteria

Before establishing traffic flow criteria, it is necessary to observe the effect of traffic flow on motorcycle accidents, with particular reference to the safety benefits of the shoulders. Accordingly, non-signalized
intersections with and without shoulders were considered for analysis. The shoulder widths were assumed to be 2.5 m. This assumption was based on the basic features of exclusive motorcycle lanes along Federal Highway Route 2 presented in an earlier study on motorcycle accidents in Malaysia [27].

The traffic flow was total traffic entering the non-signalized intersections and presented in vehicles per day in all directions. The number of motorcycle accidents was expressed in Personal Injury Accidents (PIAs) per year. Figure 2 presents the effect of traffic flow on motorcycle accidents for non-signalized intersections with and without shoulders. It can be seen that the higher the traffic flow, the more the number of motorcycle accidents, however, the intersections with shoulder has given greater safety benefit to motorcyclists compared with the ones without shoulder. These figures should enable to explore more in the relationship between major road flow, minor road flow and shoulder width.

Fig. 2. Effect of Traffic flow on Motorcycle Accidents at Non-signalized Intersections with and without Shoulder

Acceptable Limit for Motorcycle Accidents

In this analysis the traffic flow criteria was established by introducing a "particular number of motorcycle accidents" into the relationship of major road and minor road flows and shoulder derived from the model. Such number of accidents can be defined as the limit of motorcycle accidents over which countermeasures should be applied. Since the establishment of such number of motorcycle accidents involves the accident cost, the construction cost and the operation and maintenance costs of the countermeasures, the acceptable limit of motorcycle accidents may be different from country to country due to different characteristics in economics. For instance, Summersgill [28] pointed out that the provision of underpasses or overpasses (exclusive lanes) were implemented when the frequency of accidents was greater than 1.7 personal injury accidents (PIAs) per year. This figure was specifically addressed to cyclist accidents at roundabouts rather than those for motorcyclists, and the figure also was established from the economic-based point of view. Unfortunately, there were no further detailed explanations regarding this figure. In Malaysia, no such figure has been developed yet. One of the methods that may be considered for calculating this figure is described in the following paragraph.

A study on accident black spot database retrieval and prioritisation system carried out by the Road Safety Research Center, Universiti Putra Malaysia [29] outlined that locations with more than 5 accidents (all traffic accidents) within a 2-year period were considered to be a black spot, and therefore required remedial action. Royal Malaysian Police [30] reported that accidents involving motorcycles constituted about 45% of total accidents, of these, 67% were injury accidents. By using this figure, the PIAs were calculated as 0.45 x 0.67 x 5/2 = 0.754 PIAs, say, 1-PIA per year. Based on this, locations with more than 1-PIA per year for motorcyclists were identified as a black spot and need to be treated. As such, in the present study, the 1-PIA per year was considered and used to establish the traffic flow criteria. Note that intersections with shoulder widths of 2.5 m were assumed to be intersections with non-exclusive motorcycle lanes.

Figure 3 presents the relationship between the major road and minor road flows and various shoulder widths where 1-PIA per year was introduced in the relationship. It shows that wider shoulder widths at intersections offer higher levels of safety to motorcyclists approaching the junction. Different shoulder widths at non-signalized intersections shaped the differing relationships between major road and minor road flows, and this reflects the level of safety to motorcyclists generated by the shoulders. For simplification, the relationships shaped
by the non-signalized intersections with shoulder widths of 0.0 m, 1.0 m, 1.5 m, 2 m and 2.5 m were named as lines A, B, C, D and E, respectively. It can be seen that the number of motorcycle accidents of more than 1-PIA per year was expected to occur at non-signalized intersections with shoulder widths of 0.0 m when the major road and minor road flows were above line A. Therefore, line A is the border for major road and minor road flows at non-signalized intersections with shoulder widths of 0.0 m, where motorcycle accidents are expected to be no more than 1-PIA per year. Similarly, when major road and minor road flows were above line B, a figure of more than 1-PIA per year was expected to occur at non-signalized intersections with shoulder width of 1.0 m. A similar result can be observed for non-signalized intersections with shoulder widths of 1.5 m, 2.0 m and 2.5 m.

**Fig. 3. The Relationship of Major Road and Minor Road Flows at Non-signalized intersections with Differing Shoulder Widths**

Since 1-PIA per year was assumed to be the maximum number of motorcycle accidents, for practical purposes, non-signalized intersections with shoulder widths of 0.0 m should be treated using non-exclusive motorcycle lanes when major road and minor road flows entering the non-signalized intersections were in between lines A and E. Similarly, non-signalized intersections with shoulder widths of 1.0 m should be treated using non-exclusive motorcycle lanes when the major road and minor road flows entering the non-signalized intersections were in between lines B and E. Meanwhile, the major road and minor road flows in between lines C and E and lines D and E were those for non-signalized intersections with shoulder widths of 1.5 m and 2.0 m, respectively. Note that when major road and minor road flows exceeded line E, motorcycle accidents at non-signalized intersections with non-exclusive motorcycle lanes were expected to be more than 1-PIA per year. These findings form the traffic flow criteria established in this study. The criteria can be used for warranting the provision of non-exclusive motorcycle lanes at non-signalized intersections whereby motorcycle accidents are expected to be no more than 1-PIA per year.

Meanwhile, Table 3 presents typical major road and minor road flows for non-signalized intersections with shoulder width of 0.0 m and for the one with non-exclusive motorcycle lanes. The major road and minor road flows presented in this table are drawn from the relationship shown in Figure 3 (lines A and E). Thus, when major road and minor road flows exceeded the ones in column 1, motorcycle accidents were expected to be more than 1-PIA per year. To keep the expected accidents to no more than 1-PIA per year, however, non-signalized intersections with major road and minor road flows in between columns 1 and 2 should be treated using non-exclusive motorcycle lanes. Note that the other pairs of major road and minor road flows in columns 1 and 2 can be employed as long as they were respectively come from the lines A and E.
Table 3. Typical Traffic Flow Criteria for Non-signalised Junctions

<table>
<thead>
<tr>
<th>Column 1</th>
<th>Column 2</th>
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<tbody>
<tr>
<td>Junctions with Shoulder width = 0.0 m</td>
<td>Junctions with Non-exclusive Motorcycle Lanes (Shoulder width = 2.5 m)</td>
</tr>
<tr>
<td><strong>Traffic Flow</strong></td>
<td><strong>Traffic Flow</strong></td>
</tr>
<tr>
<td>Major Road Flow</td>
<td>Minor Road Flow</td>
</tr>
<tr>
<td>8000</td>
<td>9900</td>
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<tr>
<td>9000</td>
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<td>1200</td>
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<tr>
<td>26000</td>
<td>1100</td>
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</table>

4. CONCLUDING REMARKS

This study presents the effect of traffic flow and shoulder width on motorcycle accidents at non-signalized intersections on urban roads in Malaysia. Such figures were established based on the accidents prediction model developed in this study. The model reveals that traffic flow and shoulder width are significant factors in explaining motorcycle accidents at non-signalized intersections. The number of accidents is proportional to the level of traffic entering the intersections. An increase in motorcycle accidents is associated with a larger total vehicle flow on major and minor roads. Wider shoulders bring a reduction in motorcycle accidents.

The model developed in this study presents information to aid traffic engineers in deciding the appropriate level of intervention for intersection treatment with respect to motorcycle accidents. Using the model, design parameters for intersections may be changed to achieve appropriate safety levels. Decisions on whether special treatment to minimize motorcycle conflicts is needed at intersections can be objectively carried out based on the model. However, the model might only be valid for a typical traffic environment in developing countries like Malaysia, where the proportion of motorcycles is 20% to 40% of all vehicles at non-signalized intersections.

The findings, however, should encourage an in-depth investigation on the segregating motorcycles from other larger vehicles at non-signalized intersections by means of the provision of non-exclusive motorcycle lanes. Whenever possible, shoulders at non-signalized intersections should be replaced by non-exclusive motorcycle lanes. Further analysis is also suggested to find out the magnitude of traffic flow at non-signalized intersections where most motorcyclists prefer to use shoulders for riding rather than sharing traveled ways with other larger vehicles. This could reflect the demand for non-exclusive motorcycle lanes at non-signalized intersections by motorcyclists.

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