Motorcycle lane: how to judge if that is necessary

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Abstract. Malaysia has suffered great social and economic losses due to traffic injuries motorcyclists. Segregation of motorcyclists from other motorized traffic is one approach carried out in Malaysia. The non-exclusive motorcycle lane or NEMCL, is one facility provided along the major trunk roads to serve that purpose. However there are not many studies on the effectiveness of the facility thus far, especially in terms of providing justification to build the facility. This study attempted to examine the effectiveness of NEMCL by estimating the numbers of killed and seriously injured (KSI) that could be saved with the provision of the facility. Crash statistics and several key road attributes were analysed for road segments with and without NEMCL using statistical regression. Negative binomial model developed in this study revealed that NEMCL is effective in reducing the crash risk of motorcyclists. Area type, proportion of motorcycles in the traffic and the presence of NEMCL were found to significantly influence the crash rates. The model was used to develop criteria to determine the cost effectiveness of providing NEMCL for existing roads and new road projects, based on the benefits and the costs invested to build and maintain the facility over a period of time.

1. Introduction
Disorderliness on the road due to limited space for motorcycling is one of major contributing factors to the rising numbers of casualties among motorcyclists over the years. Crash statistics from 2005 to 2015 released by the Royal Malaysian Police revealed that motorcyclists (including the pillion riders) and pedestrians account for 62% on average of the total road deaths - more than half of deaths occurred on rural roads [1]. The most common types of collision that cause deaths among motorcyclists are head-on, intersection and run-off. Youths aged 16 to 30 constitute half of the total number of deaths among motorcyclists. Many of those who died are young working adults, and perhaps the only breadwinner for the family. Their contribution to the nation socio-economic progress is cut short prematurely, costing the country in lost earnings. A model developed by the International Road Assessment Programme (iRAP) estimates that the cost of fatal and serious road traffic crashes could be as large as 5% of Gross Domestic Product (GDP) for a middle income country like Malaysia [2].

Due to the greater vulnerability of this group of road users in sustaining severe injuries in the event of a crash, the motorcycle lane was built along certain stretches on the federal roads and expressways in Malaysia. Compared to an exclusive lane where motorcyclists are segregated by physical measures, a non-exclusive lane uses only painted markers or solid line for segregation [3]. The first motorcycle lane (exclusive type) in the world was built along the Federal Highway Route 2 in Malaysia in the early seventies under the World Bank Project [4], after which more and more such lanes were constructed. A study showed that such facility on average reduced motorcycle crashes by 39% and fatality by 600% [5].
Non-exclusive motorcycle lane which is without physical separator (designed as close as possible to the available design guideline) were found to have reduced motorcycle crash risk by as much as 83% [6]. Up to date, there are approximately 135km of exclusive lanes and 110km of non-exclusive lanes along the expressways and major federal roads in the country [7].

However a major challenge faced by the authorities is how to provide – in an affordable and feasible manner – a road facility that is forgiving for motorcyclists and yet does not disrupt the safe use of other road users. Crash occurrences have been reported on motorcycle lane, indicating that there is room for improvement in relation to the design and maintenance of the facilities. The cost to build and maintain the facility is no small amount and sound justifications are required before huge allocation is invested by the Government. The guideline published by the Road Engineering Association of Malaysia (REAM) in 2007 has been regularly updated to include current best practices in design, as well as research findings on the effectiveness of motorcycle lanes.

The return of investment for any construction project is extremely crucial for a developing country like Malaysia. The provision of non-exclusive motorcycle lane on new major roads should be considered if the benefits exceed or equals that of the costs incurred as far as safety outcome is concerned. The benefits can be measured in terms of the number of lives saved which is converted into values of money, termed the Value of Statistical Life (VOSL). The ratio of VOSL to the total costs of providing the motorcycle lane can be used to judge if the project should be considered. The estimation of the benefits of the motorcycle lane is thus important but still lacking in Malaysia. This paper aims to provide some evidences on the effectiveness of providing non-exclusive motorcycle lane using statistical regression approach as well as to suggest the use of criteria for deciding the provision of the facility. Hence the objectives of this study are to develop a motorcycle crash prediction model and to develop criteria for determining the return of investment of providing non-exclusive motorcycle lane (hereafter referred to as NEMCL). These criteria can supplement the use of the existing REAM guideline to justify if the safety outcome justifies the amount of investment required for a specific project.

2. Effectiveness of motorcycle lane

As mentioned above, two types of facilities are currently provided in Malaysia to segregate motorcyclists from other motorized traffic, namely the exclusive lane and the NEMCL. The exclusive lane can be found on both expressways and non-expressways while the non-exclusive lane is only built on non-expressways. Warrants for providing these facilities are included in Guidelines for Motorcycle Facilities published by REAM in 2011, criteria of which include crash history and traffic volume. Other considerations include the number of access points and junctions, as well as type of carriageway [3].

Despite these warrants, various designs of the lane are found across the country, prompting investigation into the effectiveness of each design. The effectiveness of the lane in reducing crash and injury risk among motorcyclists greatly depends on the usage, in addition to its characteristics. Besides, factor such as prevalence of misuse by other vehicles could also contribute to the measure of effectiveness of the facility, especially the non-exclusive type. Unfortunately research works in these areas is lacking in the country. A study by revealed that benefits of providing the exclusive lane far outweigh the costs of building and maintaining it, by about 3 to 5 times [4, 8]. This study compared the annual savings made from preventing crashes with the estimated costs of initial implementation and annual maintenance costs. The benefit-to-cost ratio (BCR) values, which were more than one clearly show that provision of the exclusive lane is a highly cost effective countermeasure in addressing motorcycle safety issues.

On the other hand, to the best knowledge of the authors, no published work which examines the effects of NEMCL on crash and injury risk has been found in the literature. As such, no conclusion can be made thus far on the potential of the facility in reducing motorcycle related crashes. In fact, crash records published by the Royal Malaysia Police for 2006 and 2007 showed that there was an increase in motorcycle fatalities on roads with the facility [6, 9]. Many factors should be considered in determining the effectiveness of such facility, particularly the usage rates among motorcyclists. It is bias to expect a
reduction in motorcycle related crashes on road sections with such facility where the compliance rate is low. Certainly the crash risk of motorcyclists would not decrease if they still remain in close contact with other vehicles on the main lanes although they are given a chance to distance themselves. The effect of junctions on the usage rates of paved shoulder by motorcyclists was studied in an earlier work where continuous paved shoulder at junctions can reduce conflicts between motorcycles and other vehicles [10]. Besides increasing the usage rates, the treatment was also found to be able to reduce motorcycles’ average and operating speeds in the vicinity of junctions. Though it can act as means for segregation, the law, except for emergency situations, does not permit the use of paved shoulder by motorcyclists.

Many studies on motorcycle safety worldwide were carried out to identify contributing factors and several developed crash prediction models using crash data in Malaysia. These models revealed that the design of the road environment as well as the traffic speed contributed significantly to the crash rates [11, 12, 13, 14, 15]. However none of these studies covered the effect of NEMCL, which may probably due to the limited crash data occurring on road sections with the facility. Moreover the pure effectiveness of NEMCL in influencing the crash rates is difficult to be assessed due to other factors that exist within the road and traffic system. Many of these factors especially related to the riding behaviour are complicated to be studied and as such very often unobserved or purportedly omitted from the analysis. Nevertheless such regression techniques are still useful to provide indications as to how a road attribute influence the crash outcomes, as far as motorcycling safety is concerned.

One advantage of using regression modelling in road safety studies is the ability of deriving crash modification factors (CMFs). A CMF for a countermeasure indicates the proportion of the expected number of crashes after the implementation of the countermeasure at a specific site [16]. Depending upon the study from which the CMF is estimated, it can be developed and applied for all crash types and locations, as well as for specific site characteristics, crash types and severities. It is of course more beneficial if CMFs are developed for each site condition, each crash type or each crash severity as more accurate estimation can be performed in a cost-benefit analysis. CMF had been developed and used in road safety engineering for quite a number of countermeasures. All these CMFs were developed based on studies on the effectiveness of each countermeasure to reduce crashes. A CMF can be in the form of a numerical value, equation, graph, or a combination of these.

3. Data and methods
3.1. Road segmentation and crash data
In order to achieve the specific objectives of this study, sections along major federal roads with NEMCL were identified based on information obtained from the Public Works Department (PWD). Together with the availability of survey data collected from the iRAP Malaysia Pilot Study, the following road sections were selected for this study:
1. Federal Route 1 from Gurun to Sungai Petani.
2. Federal Route 5 from Pekan Nenas to Batu Pahat.

The location of motorcycle related crashes (fatal and serious injury) obtained from the Royal Malaysia Police for the selected road sections from 2009 to 2015 were compiled and plotted on a map. Using the survey data from the pilot study, which recorded attributes for every 100 m, the observed routes were further segmented based on characteristics shown in table 1. The number of crashes were then recorded for each road segment.

3.2. Regression modelling
It has become a standard practice to use statistical models to describe and predict the occurrence of road crashes based on traffic volumes and road geometrics. Traffic engineers have been using such approach to decide on the appropriate countermeasures to be implemented. However, majority of these models are developed by conventional linear regression techniques which contain inherent errors that limit their application and accuracy [17]. Due to the limitations, Poisson and Negative Binomial regressions were considered in this study.
An exponential function is a common formulation, since this function ensures that the expected number of crashes is a positive number. Thus, crash frequency may be written as a multiplicative function for which the value of the exponents can be estimated directly by measuring the explanatory variables on the logarithmic scale as in Equation 1 where $\beta$ is the coefficient estimation and $X_i$ are the independent variables, e.g. road traffic properties such as traffic volume, percentage of motorcycles or area type, etc.

$$E(Y) = \exp \left[ \sum \beta_i \ln(X_i) \right]$$

(1)

### Table 1. Road attributes used in segmentation.

| Factors               | Description                                      | Source of data                              |
|-----------------------|--------------------------------------------------|---------------------------------------------|
| Traffic volume        | Average of 16 hours manual count conducted twice annually | Highway Planning Division, Ministry of Works |
| Traffic composition   | The percentage of motorcycle in traffic stream   | Highway Planning Division, Ministry of Works |
| Area type             | Urban or rural                                   | iRAP Malaysia Pilot Study survey data       |
| Carriageway type      | Single or dual                                   | iRAP Malaysia Pilot Study survey data       |
| Number of lane        | One, two or more than two lanes in each travel direction | iRAP Malaysia Pilot Study survey data       |
| Access point density  | The number of access point per kilometre         | iRAP Malaysia Pilot Study survey data       |
| Presence of NEMCL     | Yes or no                                        | iRAP Malaysia Pilot Study survey data       |

3.3. Development of motorcycle lane provision criteria

The crash prediction model developed based on the crash history of motorcycle crashes recorded along the study sites was used to generate criteria for the provision of motorcycle lane. These criteria were developed on the principle of ensuring positive return of investment, whereby the savings in terms of the number of lives saved equals to or exceed the total cost of constructing and maintaining the facility over a period of time. The benefits of lives saved used were estimated in the form of money, derived from the value of statistical life (VOSL) of an average Malaysian. In road safety, the VOSL is widely used to estimate the burden of socio-economic losses to a country based on the gross domestic product per capita of the people in that particular country [18]. On average, the VOSL (a fatality) is estimated by the following equation:

$$VOSL = 70 \times GDP/capita$$

(2)

Thus, the savings in the cost of crashes is calculated by multiplying the VOSL with the expected number of fatalities saved after a treatment is implemented. In this study, the difference between the expected number of fatalities on a road section with and without motorcycle lane is taken as the number of fatalities saved due to the provision of motorcycle lane (conservatively assuming that a single KSI crash will involve a single fatality).

The difference between the expected number of fatality, $D$ was calculated using the crash prediction model for each level of motorcycle percent as follow:

$$D = E(Y_0) - E(Y_1)$$

(3)
Where \( E(Y_0) \) is the expected number of KSI crashes at sections without motorcycle lane and \( E(Y_1) \) is the expected number of KSI crashes at section with motorcycle lane.

The total value of \( D \) as calculated using the VOSL will determine the associated total cost of constructing and maintaining the motorcycle lane for different benefit-to-cost ratios (BCRs). A BCR value of one means that the total values of lives saved equals that of the total cost of providing the motorcycle lane, which ought to be the minimum return of investment to be considered. The criteria when the benefits are expected to be two and three times the costs (BCR = 2 and BCR = 3) were also generated.

4. Results and discussions

4.1. Effectiveness of NEMCL

A total of 88 road segments were generated with a total length of 77km ranged between 0.1km and 8.0km. The breakdown in table 2 shows that the percentage distribution of all controlling road attributes was not fairly equal. This is because of the difficulty in identifying road segments with similar characteristics in the vicinity of NEMCL. However the distribution is sufficient enough for statistical modelling purposes except for the number of lane where segments with more than one lane constitute only less than 20%. As such this variable was not considered in the regression analysis. Table 3 shows the descriptive statistics of these variables.

| No. | Attributes                              | Breakdown |
|-----|----------------------------------------|-----------|
| 1.  | Traffic volume (AADT)                  |           |
|     | 10,000 – 20,000                         | 32%       |
|     | 20,000 – 30,000                         | 25%       |
|     | 30,000 – 40,000                         | 25%       |
|     | 40,000 – 50,000                         | 18%       |
| 2.  | Motorcycle percentage (%)              |           |
|     | Less than 20%                           | 52%       |
|     | More than 20%                           | 48%       |
| 3.  | Area type                              |           |
|     | Rural                                  | 33%       |
|     | Urban                                  | 67%       |
| 4.  | Number of lane (each direction)        |           |
|     | One                                    | 83%       |
|     | More than one                           | 17%       |
| 5.  | Access point density (no. per km)      |           |
|     | Less than five                          | 50%       |
|     | More than five                          | 50%       |
| 6.  | Presence of NEMCL                       |           |
|     | Yes                                    | 60%       |
|     | No                                     | 40%       |

The variance of the crashes per km variable is far greater than its mean, and therefore Poisson model would not be the best choice. The negative binomial model instead was used to develop the crash prediction model. An analysis of correlations among the variables was performed to determine if high collinearity occurs among them. If collinearity occurs between two variables, one of them can totally predict the other and vice versa. In other words, a regression model with highly correlated variables (considered to be when the Pearson correlation value is more than 0.5) can only predict how well the
entire set of independent variables predicts the dependent variable, but may not provide the true effect of each individual correlated variable. The correlation analysis showed that the traffic volume and motorcycle percentage were highly correlated. Due to the importance of traffic volume in any crash prediction model, it was included in the analysis initially but was found to be not significant. Table 4 shows the regression coefficients for the best fit model with three predictor variables. An interaction term between motorcycle percent and presence of NEMCL was introduced to examine the effects of motorcycle percentage on crash outcome with and without NEMCL. Note that the dispersion parameter was found to be significantly different from zero which confirms that the negative binomial distribution offered better prediction than the Poisson model.

Table 3. Descriptive statistics of variables included in regression analysis.

| Continuous variables         | Minimum | Maximum | Mean  | Std. Dev. |
|------------------------------|---------|---------|-------|-----------|
| Number of total KSI crashes/km | 0       | 8       | 2.0   | 2.3       |
| Traffic volume (AADT) (aadt) | 11133   | 43306   | 27097 | 10489     |
| Motorcycle percentage (%) (mcpct) | 12      | 28      | 20    | 6         |
| Access point density (no./km) (apd) | 0       | 35      | 7     | 7         |

| Categorical variables | Description | Percentage |
|-----------------------|-------------|------------|
| Area type (area)      | Rural       | 33         |
|                       | Urban       | 67         |
| Presence of NEMCL (mclane) | Yes     | 60         |
|                       | No          | 40         |

Table 4. Regression coefficients for the best-fit model.

| Variables               | Estimated coefficient$^a$ | z-statistics | Confidence Interval |
|-------------------------|---------------------------|--------------|---------------------|
| Constant                | 0.220 (0.547)             | 0.40         | -0.852              | 1.292                |
| Area (area)             | 0.736 (0.435)$^c$         | 1.69         | -0.117              | 1.589                |
| Presence of NEMCL (mclane) | -1.142 (0.452)$^b$   | -2.52        | -2.028              | -0.255               |
| mcpct.mclane            | 0.029 (0.134)$^b$         | 2.12         | 0.002               | 0.056                |

$^a$ standard errors are in parentheses
$^b$ significant at 95% confidence level
$^c$ significant at 90% confidence level

The regression results revealed that area type, percentage of motorcycle and presence of NEMCL were significant in influencing the crash rates among motorcyclists. As expected, urban area was found to have higher crash rates due to the higher traffic volume (including higher proportion of motorcycles) and higher access point density, in line with an earlier study conducted on Malaysian primary roads [15]. Despite having no detailed crash information on the location of those motorcycle crashes (whether occurred on NEMCL or out of NEMCL), these results suggest that the presence of NEMCL had proven effective in reducing motorcycle crash rates (note the negative coefficient of variable mclane). This is
strongly believed to be due to the fact that the usage of the facility is high among motorcyclists [19]
which decreases the likelihood of being hit by other motorists.

However the results indicated that the effectiveness of NEMCL is higher when the percentage of
motorcycle is low. When the percentage of motorcycle increases, the effectiveness of NEMCL slightly
reduces (note the positive coefficient of the interaction term variable of mcpct.mclane), which may
probably due to more motorcyclists not using the facility as the occupancy increases. As such the
likelihood of motorcycle crashes become higher whenever its percentage increases despite the presence
of NEMCL especially in urban areas. In other words, the provision of NEMCL alone is not enough and
should not be treated as the only intervention to tackle motorcycle crashes in urban areas.

For a better representation of the regression results, the model can be written as:

\[
\text{Crashes/km} = e^{0.736(area) + 0.029(mcpct.mclane) - 1.142(mclane)} \quad (4)
\]

Where:
- \( area = 1 \) when the area type is rural; \( 2 \) when the area type is urban
- \( mclane = 1 \) when NEMCL is not present; \( 2 \) when NEMCL is present

4.2. Development of motorcycle lane provision criteria

The model developed in this study was used to develop justification criteria for provision of NEMCL.
As the costs for building and maintaining the facility vary by locations, these criteria were developed
with the aim of providing an alternative consideration to build the based on the current costs. The
estimated costs to build an extra lane (both directions) including the necessary road marking and traffic
signs were RM2 million per km (in urban areas where adequate shoulder width is usually limited), and
RM400,000 (both directions) for separator marking and road studs (in rural areas where adequate
shoulder width is converted to NEMCL). The minimum criteria therefore would be taken as when the
costs equal the safety benefits in terms VOSL. The VOSL for an average Malaysian was determined to
be RM2,953,930, based on the GDP/capita of RM42,199 for Malaysia in 2017 [20].

In developing the criteria, the number of fatality saved was taken as the difference in the number of
KSI crashes between with and without NEMCL at every level of motorcycle percentage. Based on the
develop model above, the maximum fatality saved is 1/km (with a value of RM2,953,930) for urban
area and 0.5/km (RM1,476,965) for rural area. Therefore, the maximum BCR that could be obtained is
about 1.5 for a 1km section of urban area and 3.7 for a 1km section of rural area. These BCR values
however will subject to change depending on the current costs of providing the facility, the percentage
of motorcycles as well as the GDP/capita.

Figure 1 and Figure 2 show the criteria developed for urban and rural areas for a range of motorcycle
percentage. The range used was limited by the samples of the 88 road segments included in this study.
BCR values of 1 to 3 were used to reflect the practical range achievable based on the model developed.
The lowest criteria that should be considered was when BCR = 1 as the benefits obtained will be equal
to the cost incurred. For example, in urban area and when the motorcycle percentage is 20%, the cost to
construct and maintain the NEMCL per km over a 7-year period must not exceed RM3,155,000. The
return will be twofold if the cost can be kept at RM1,577,000 at the same level of motorcycle percentage.

Based on these criteria, the limits in the cost for providing and maintaining NEMCL per km is less
rigid for urban area. This is because of the higher crash rates observed in urban areas, and thus the
estimated number of fatality saved was also higher. In other words, the value of benefits are higher if
NEMCL is provided in urban area. For example, if RM1,000,000 is allocated to provide NEMCL, the
return of investment will be RM3,000,000 for urban areas compared to only RM1,700,000 for rural area
with 20% motorcycle.

These criteria can be used as a tool to justify allocation and put up a business case for the government
to spend on NEMCL, which supplements the existing warrants stipulated in the REAM guideline. These
criteria provide scientific evidence on the safety benefits that can be achieved with available level of
funding for various levels of motorcycle composition. It can be useful for new road projects or even for
upgrading of existing roads where information on the costs and traffic composition are readily available.
5. Conclusions

This study aims to examine the safety effectiveness of non-exclusive motorcycle lane as well as to generate criteria for provision of the facility. A total of 88 road segments were identified based on several road attributes that include the presence of NEMCL along several sections on FT001 and FT005. These segments were identified in the vicinity of NEMCL in various length. Motorcycle crash data from 2009
to 2015 were compiled and mapped along these road segments to produce a dataset for statistical regression analysis. The negative binomial distribution was found to be able to fit the crash data with several road attributes. The type of area, the percentage of motorcycle and the presence of NEMCL were found to have significant effects on the crash rates.

The regression results revealed that area type, percentage of motorcycle and presence of NEMCL were significant in influencing the crash rates among motorcyclists. Regardless of the presence of NEMCL, the model showed that crash rates was significantly higher in urban areas due to high traffic exposure. The presence of NEMCL was found to be effective in reducing motorcycle crash rates by increasing the separation between motorcyclists and other motorized traffic. The high utilization rate of the facility as revealed by an earlier study confirmed the effectiveness of NEMCL. However this study did not account for the effect of the design of the facility which influences the utilization rate.

In order to study the return of investment for providing NEMCL, this study developed criteria based on the motorcycle percentage and the overall construction cost for urban and rural areas. The limiting criteria were based on three BCR values (BCR = 1, BCR = 2 and BCR = 3). These criteria can be used to judge if provision of NEMCL is necessary for new road projects or existing roads based on the estimated cost required and the expected motorcycle composition in the traffic stream. The lowest return of investment is when the safety benefits equals that of the total cost to construct and maintain the facility. As such in any given project requirements, the provision of NEMCL can be decided based on the BCR values obtained through these criteria. Also, the BCR values can be used to identify priority among various development projects, especially when available budget is limited.

The use of only 88 road segments may not be sufficient to portray the effectiveness of NEMCL in reducing crash rates. It is recommended that more road segments are used, with good representation of the various design of NEMCL. Good quality of crash data will definitely improve the model accuracy. But as far as this study is concerned, the available evidence gathered so far by the police (crash data), Highway Planning Division (traffic data) and MIROS (road attributes) revealed that NEMCL is recommended especially in urban areas.

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