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Accident Prediction Model by Relating Integrated Design Consistency Model

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Abstract: The number road accident kept rising in every year in Malaysia. In early 2016, Johor has been mentioned as the among highest-ranking road accident at hazard road locations. The main accidents occur are a road accident with passenger cars, road accident with other motorcycles and single-motorcycle road accidents. Furthermore, the problem road accident on hazard road location are still unsolved, especially for main road accident types of vehicle; motorcycles and cars. The study location segments were selected at Johor Federal Route 50; KM1- KM5. Therefore, this study using an accident prediction model by relating integrated design consistency model, through a comprehensive speed characteristic using a global positioning system and based on an operating profile to develop a continuous speed profile between motorcycles and cars and to determine design consistency models. Poisson model is used to relate road design consistency models and accident rates to evaluate the impact of design consistency with road safety.

Keywords: Accident, design consistency, speed profile, Poisson model, Federal Road Johor

1. Introduction

Every year almost 1.25 million people around the world involve with road accident. Among 20 and 50 million people are suffering serious injury, slightly injury and disability based on road accident occurring (WHO, 2015). Besides that, WHO stated road traffic accident can causes one million people are died, three millions are severely are disabled for life, and thirty millions are injured. By 2020, road accidents will be the third leading cause of death worldwide. In developing country, every year shows that road accidents are kill more people than war and virus. Furthermore, in Asia continent only, almost 400,000 people are died on the roads and more than four million injured every year. The causes of road accident are based on imperfect vehicles, irregular roads, careless driving, speeding, drunk driving, not enough sleep, under the influence of alcohol and other drug effect and many more. For that reason, road accidents in Malaysia are one of the most relevant issues in today's civilization and one of the main causes of death and injuries. In the middle of the ASEAN, Malaysia has the highest road accident risk and more than 50% of the road accident fatalities involves motorcyclist, and the numbers of traffic accident kept rising. Every year, the numbers of traffic accidents that were recorded in Malaysia are growing The West Coast Area of Malaysia is the highest motorcycle fatalities due to the highest

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number of registered motorcycles and population. As the entire of motorcycle billion kilometers travelled in Malaysia increased from 1990 to 2008, motorcycle fatalities increased as well.

The number of road users is increased roughly in the last past years and the amount of traffic accidents that were recorded in Malaysia are rising about 300 00 accidents reported and 1% of fatal accidents for every year [1]. The increase in motorization lead to a resulting increase in the number of road accidents and the most popular road accidents in Malaysia is by involving road accidents with passenger cars, road accident with other motorcycles and single-motorcycle accidents [2]. Motorcycle fatalities represent more than 60% of the total fatalities in traffic accident and more than sevenfold compared to passenger cars. It represents that 29% were fatal, 56% required hospitalization and 15% sustained slight injured [3]. There were 6674 road fatal in 2014, and its decrease about 3.5% compared to 2013. However, in 2013, motorcyclist rides represented 62% of all fatalities meanwhile car drivers and passengers represented 20% of fatalities [4].

The among the use of a motorcycle compare other's road vehicle users, it has the possibility of disclosure in a road accident because riders are straightforwardly uncovered and come in direct contact with the other vehicles or obstacle during an accident and resulting in severe injuries and fatal [5]. In addition, at the side of the road accident increase between motorcycles and passenger cars, an unresolved problem is about road accident at hazardous location usually based on accident data. Road can be classified as hazardous in term of road hazard that referring to any fixed object by the side of the road. Road design failure can be physical defects in the road, such as potholes, intersection, including driveways, curves or bends in the road, the position or movement of other road users, lack of appropriate road markings, improperly graded curves and uneven shoulders [6]. Therefore, to overcome the problem road accident between motorcycles and cars in Malaysia, this study developing an accident prediction model at hazardous locations with relating to the number of road accidents, geometric elements and integrated road design consistency model between motorcycles and cars at Johor Federal roads.

2. Design Consistency Estimation

Design consistency is the relationship between the geometric characteristics of a highway and the conditions that the driver expects when their drive. When the design is consistent with the driver expects, the highway is also consistent [7]. One of pervious study have put forward a new model of consistency based on data through continuous speed profile and it relate the speed profile with the geometric variables of the road segment and with accident statistics for the segment [8]. Models are based on operating speed to calculate design consistency of road. Operating speed are defined as the speed selected by the drivers when no restricted by other users or speed under free flow conditions and normally represented by the 85th percentile speed, V_{85}. By estimating the 85th operating speed variation along the road, it produces continuous speed profiles. The profiles were obtained by considering continuous speed profile using GPS devices and continuous speed profiles are used to determine the global speed variation along a road segment and determining a single consistency value for the whole road segment. The method explains consistency is essentially by means of speed standard deviation and R_a value.

According [8] purposed new method to check design consistency. Parameters for this model are the bounded area between the profile and the average speed along a two-lane highway segment. As a design consistency increased, crash rates will decrease significantly. The corresponding equations are

$$R_a = \frac{(\sum a_i)}{L} \quad (1)$$

where R_a is relative area (m/sec) measure consistency, $\sum a_i$ is sum of i areas bounded between the speed profile and the average operating speed (m^2/sec), L is entire segment length (m).

$$\sigma = \left\{\frac{(V_j - V_{avg})}{n}\right\}^{0.5} \quad (2)$$

where Σ is standard deviation of operating speeds (km/h), V_j is operating speed along the j^th geometric element (tangent/curve) (km/h), V_{avg} is average weighted (by length) operating speed along a segment (km/h), n is number of geometric elements along a segment (km/h).

$$V_{avg} = \frac{\sum V_i L_i}{\sum L_i} \quad (3)$$

where V_{avg} is average weighted (by length) operating speed along a highway segment (km/h), V_i is operating speed (km/h), L_i is length of segment (km).

3. Integrated Design Consistency Estimation

Design consistency is the relationship between the geometric elements of a road and the conditions that the driver expects when they drive. When the design is consistent with the driver expects, the highway is also consistent according the driver [7]. Consistency methods are based on the changes of speed along geometric elements from the average speed of vehicles. A plot 85th percentile operating speed along the distances are stated as a continuous speed profile. Speed profile was developed through the operating speed model along the j^{th} geometric element [8]. The consistency is essentially by means of speed standard deviation and Ra value. It proposed new measured to check design consistency. The first measures (R_a), is the relative area (per unit length), bounded between the speed profile and the average speed line (V_{avg}). It can be practical to individual speed profile or to the operating speed profile (V_{avg}). The secondly, measures was the standard deviation of operating speed in each design element along the whole section investigates (σ). By Adding the bounded area (A_{CT}) is equally related to the improvement in the design consistency of the road for vehicles, the smaller the bounded area, the better the design consistent performance of two types of vehicles [9]. The speed profiles were obtained by continuous speed using GPS devices which allowed accurate determination of the start and end points of speed transitions from individual drivers and riders. It's only obtaining continuous speed profile by using global positioning system, GPS and the continuous speed profiles are based on relative area (R_a). The profiles allow the development of speed-geometry models are used to generate speed profiles on long road segments and it provides current techniques for speed profile development [10].

4. Accident Prediction Model

Poisson regression are the relationship between accident frequency and the risk factors, hence the models are an effective maintenance strategy tool or as a pre-selection tool for road safety audit and maintain the road features [11]. Poisson model is estimated by the maximum likelihood method where it estimates are adapting to the actual data. Compared to normal model, the Poisson model gives a better estimate of the counts. [12]. The models were developed by taking accident as dependent variables and the factors which cause the accident as independent variables. It assumes that the mean and variance of the errors is equal [13]. Some studies conclude that Poisson models are more appropriate tool in accident modelling and acknowledged that conventional linear regression models are not appropriate and error for modelling vehicle accidents events on roadway and test statistics [14].

5. Method

The purpose of the study is to develop an accident prediction model at hazardous locations with relating to the number of accidents and integrated road design consistency model between two vehicles.

5.1 Site Location

The site location is in the among the highest accident at hazard location by using ranking by accident point system based on weighted adopted and police data. The site location at FT 050 are segmented at KM1 until KM5 as can be seen in Fig. 1 to Fig. 5.

Fig 1 - Location KM1 FT 050

Fig - Location KM2 FT 050

Fig 3 - Location KM3 FT 050

Fig 4 - Location KM4 FT 050

Fig 5 - Location KM5 FT 050

5.2 Data Collection

Primary data was involved of data speed of two vehicles, by using 100 of test drivers and motorcyclist. The data were collected through the test driver and riders method using the same moving vehicle and following their normal driving habits who were not familiar with the routes and no instructions were given. There were only small size of GPS as an instrument in vehicles which were considered safe for the drivers and motorcyclists. Secondary data were involved of three parts; accident data, geometric data and average annual daily traffic (AADT). The accident data are included of fatal, severe injury and slight injury. The geometric data are included of the length of the tangent or curve, lane width, shoulder width, median width and access point.

5.3 Data Analysis

The 85th percentile speed was determined in order to develop operating speed model for predicting the operating speed. Hence, the equation (1) shows as:

$$V_{85} = A_1 + A_2 \text{ (L)} + A_3 \text{(AP)} + A_4 \text{ (SW)} - A_5 \text{ (Q)} \tag{4}$$

where; A_1 = speed of vehicle (km/h), L = length tangent/curve (m), SW = shoulder width (m), AP = access point and Q is median. Profile was plotted using continuous speed data obtained from GPS DG-200. The models are developed based on the new method of speed profiles analysis. The speed models are based on empirical data which were commonly used in several studies of mixed traffic conditions [12, 13]. The following studies use an operating speed at 85th percentile. Model prediction of 85th percentile speed for tangent and curve are using multiple linear regression method to developed prediction operating speed model for motorcycles and cars.

For motorcycles:

$$V_{85t} = 81.9 + 12.5\ L_T - 3.55\ SW - 2.16\ AP,\ R^2=0.74 \tag{5}$$

$$V_{85c} = 80.5 + 8.80\ L_C - 4.04\ SW - 0.42\ AP,\ R^2=0.95 \tag{6}$$

While for cars:

$$V_{85t} = 77.0 + 1.69\ L_T + 4.65\ SW - 2.49\ AP,\ R^2= 0.68 \tag{7}$$

$$V_{85c} = 76.4 - 2.57\ L_C + 0.88\ SW - 0.47\ AP,\ R^2= 0.33 \tag{8}$$

where V_{85t} = Operating speed of tangent, V_{85c} = operating speed of curve, L_t= length of tangent, L_c = length of curve, SW = shoulder width, AP = access point. Based on the previous study, the parameters for this model are the bounded area between the profile of the average speed along a two-lane highway segment [9,15] and determine the model of consistency (C) and the model integrated design consistency [9,16] based on equation; where C has a unit of m/s as it is mainly based on the speed consistency of vehicles that shows in a function of Ra (m/s) and σ (m/s):

$$C = 2.808.e^{(-0.278.R_a.\sigma)} \tag{9}$$

where, C is road consistency per segment, R_a is normalized area bounded by the average speed profile of two vehicles and the average operating speed (m/sec), σ is standard deviation of vehicles speeds (m/sec).

$$IC = \left[2.808 * e^{(-0.278 * R_a * \sigma)}\right] * e^{(-0.01 * A_{CT})} \tag{10}$$

where; IC is integrated consistency of road segments , R_a is normalized bounded area by speed profile of two vehicles and the average operating speed (m/sec), σ is standard deviation of vehicles speeds (m/sec), A_{CT} is normalized bounded area between the speed profile of two vehicles (m/sec). As “a” is bounded area (speed * distance) and L (distance), therefore, Ra will be in unit of m/sec. The integrated design consistency model according the segments was determined based on range by [9], [16] is:

Table 1 - Design Consistency Value

Design -consistency value		
Good	Acceptable	Poor
C > 2 (m/s)	1< C ≤ 2 (m/s)	C ≤ 1 (m/s)

The accident prediction models was developed by taking road accident as dependent variables and the others elements [17] which cause the accident as independent variables, the model shows as an equation:

$$\mu = e^{(x_i \beta)} \tag{11}$$

where, x_i is the vector of the explanatory or independent variables and β is the vector of unknown regression parameters.

6. Results and Discussion

6.1 Operating Speed Model

Multiple linear regression technique was used to describe a statistical relationship between a dependent variable and independent variable by using Minitab Software. Dependent variable such as speed of motorcycles and cars and independent variable such as the length of the tangent, length of curves, shoulder width, median and access point was used to develop an operating speed model. The equations operating speed model has developed as shown in equation:

$$V85M = 94.1 - 13.2\ L + 0.564\ AP - 8.27\ SW - 3.43\ Q \tag{12}$$

$$V85C = 95.7 - 6.30\ L - 0.535\ AP - 5.59\ SW - 1.89\ Q \tag{13}$$

where, L = length of tangent or curve, SW = shoulder width, AP = access points, Q = median, V85M = operating speed model of motorcycles and V85C. = operating speed model of cars. The regression coefficient of motorcycles shows that the coefficient for the length of distance (tangent and curve), access points, shoulder width and the median has a negative sign, therefore it's causing that an increase in the length of distance (tangent and curve), access points, shoulder width and median it will lead to a decrease in the operating speed for motorcycles. The regression coefficient of cars shows that the coefficient for the length of distance (tangent and curve), shoulder width and median has a negative sign. Increasing in the length of distance (tangent and curve), shoulder width and median will lead to a decrease in the operating speed for cars and variable of access point has a positive sign implying that an increase operating speed at the segments, will lead to an increase operating speed of cars.

The continuous operating speed profile models were plotted based on operating speed model (85th percentile). Plots of operating speed model profile (85th percentile) along the length are called as speed profile for this study. ACAD software was used to developed road design consistency model. The consistency was calculated for each segment from the speed profile. Fig. 6 shows speed profile FT050 of motorcycles at km1 – km5. Fig. 7 shows speed profile FT 050 of cars at km1 – km5.

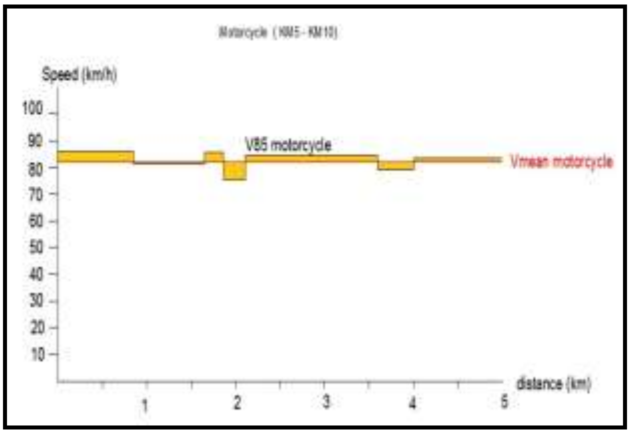

Fig. 6 - Speed profile FT 050 of motorcycles (KM1 _ KM5)

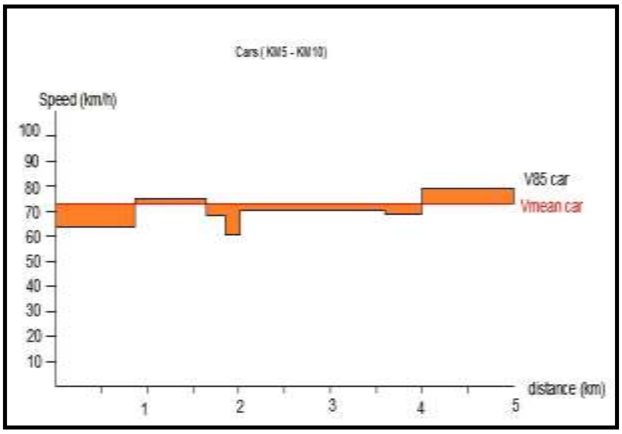

Fig. 7 - Speed profile FT 050 of cars (KM1 _ KM5)

The consistency index was estimated based on speed profiles. To estimate consistency index of eq. (9) two parameters were considered. First the value of standard deviation, σ was obtained using the operating speed. Second the bounded area between the profile and the average speed. Table 2 shows design consistency motorcycles at km1 – km5 per km. Table 3 shows design consistency cars at km1 – km5 per km. The design consistency model for motorcycle and cars shows the threshold of design-consistency quality is good design. This is based on road features conditions in this area for motorcycles and cars.

6.2 Integrated Design Consistency Model

The integrated design consistency model (*IC*) is to know the impact of speed profiles between motorcycles and cars in design consistency. Meanwhile, design consistency model is based on two main parameters; the bounded area between the profile and the average speed and secondly are the standard deviation of speeds along a selected segment and A_{CT} is bounded area between the linear speed profiles of cars and motorcycles. The integrated design consistency model between a continuous speed profile of cars and motorcycle at KM1 until KM5, Federal Route 50 are shown in Fig. 8 and Fig. 9.

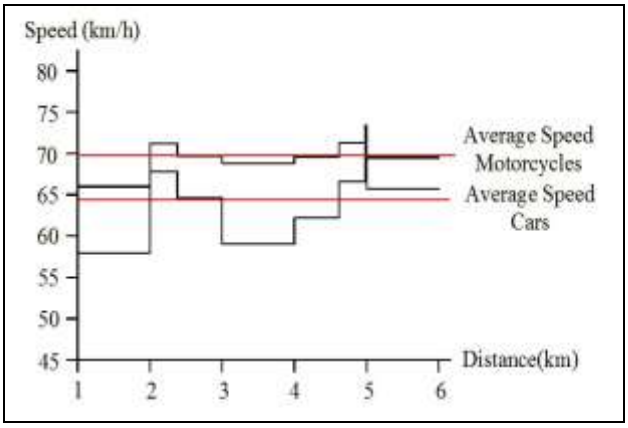

Fig. 8 - Continuous Speed profile FT 050 between motorcycles and cars (KM1 _KM5)

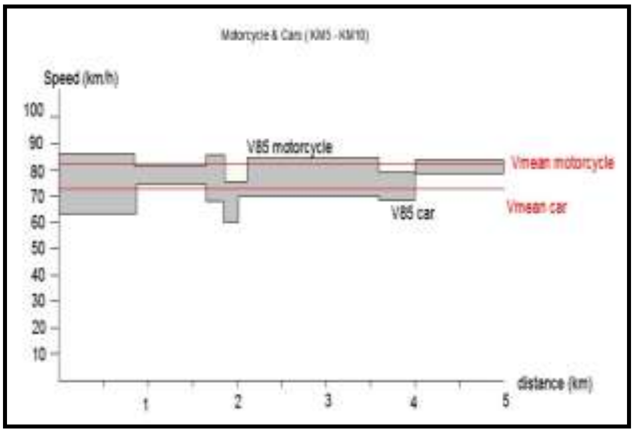

Fig. 9- Integrated speed profiles cars - motorcycles

The models were developed with 1 km road segments where most of the cases were tangent section. Therefore, the study found that it should be a model for each of the segment. From the Table 2 and Table 3, road conditions at KM1 for motorcycles show acceptable consistency where the consistency is between 1 and 2 were an average acceptable design consistency range at road FT 050 and car shows poor consistency was less than 1 in an inconsistent design range at road FT 050. Nevertheless, road conditions at KM2 and KM 5 show good consistency range for both vehicles are greater than 2 in a consistent design at road FT 050 (KM1 – KM5). Meanwhile a road condition at KM3 for motorcycles shows good consistency greater than 2 in a consistent design range at FT 050 while cars show poor consistency, which is an inconsistent design range. Road condition motorcycle at KM 4 shows good consistency are greater than 2 in a consistent design range and car show acceptable consistency range between 1 and 2 were an average acceptable design consistency at FT 050.

Table 2 - Design Consistency Motorcycles (KM1 – KM5)

Km	Design Consistency	Threshold
1	1.52	Acceptable
2	2.55	Good
3	2.39	Good
4	2.48	Good
5	2.68	Good

Table 3 - Design Consistency Model Cars (KM1 – KM5)

Km	Design Consistency	Threshold
1	0.67	Poor
2	2.06	Good
3	0.86	Poor
4	1.70	Acceptable
5	2.11	Good

A road segments of KM1 until KM5, it was located next to traffic lights, intersection and the access point along segments and it's near to the shops, Klinik Kesihatan and the temple and also the authority area are busy and it's given the affected speed of motorcycles and cars. However, the geometric elements such as shoulder width, lane width, and median and access point are gave the influence of speed of motorcycles and cars. Hence, the probability of road accidents occurs between motorcycles and cars along a road segment are higher because the conditions of the shoulder width and the lane width are not uniform along road segments and several of access points. From the Table 4, road segments at KM1 and KM3 are showing poor consistency range between motorcycles and cars where it is an inconsistent design for both vehicles at segment KM1 and KM3. Meanwhile an acceptable consistency shows average acceptable design consistency range between motorcycles and cars at road segments KM2 and KM4. Lastly, KM5 is showing good consistency where the road consistency greater than 2 in a consistent design range between motorcycles and cars. The probability of road accident occurred between motorcycle and cars are higher in this segment at KM1 – KM5 because the presence of access points, improper shoulder width and lane width. The increasing number of access points along a segment are given the expected number of road accidents occurs [18, 19]. The study is conducted at Federal roads in Johor where access point are not limited and the previous studies show AP is a significant parameter for traffic quality and safety at FT050. It also show good R^2 and well calibrated. The improper shoulder width would cause number of road accidents and road accidents would increase considerably with a decrease in lane width along segments [20-22].

Table 4 - Design Consistency Model between Motorcycles and Cars (KM1 – KM5)

Km	Design Consistency	Threshold
1	0.62	Poor
2	1.97	Acceptable
3	0.78	Poor
4	1.60	Acceptable
5	2.03	Good

6.3 Accident Prediction Model

By relating integrated road design consistency model, geometry elements and accident rates, it is potential to estimate accident prediction models. Therefore, R statistical software is used for the analysis. The Poisson regression model is developed to estimate the accident prediction model in road accidents as an equation:

$$T = e^{(1.2136 + 07024LW + 0.5624IC)} \tag{14}$$

where, T = road accident prediction, SW = shoulder width and IC = integrated road design consistency. The positive coefficient of the integrated road design consistency model (IC) and shoulder width indicates as the integrated road design consistency and shoulder width increases, therefore the number of road accidents increases too and the improper shoulder width would cause increases number of road accidents.

7. Conclusions

The consistency of the geometrical can be defined the synchronization between drivers' expectancy on the road and geometry. Continuous speed profile data that collected using Global Positioning System (GPS DG-200) equipment under free flow condition for develop design consistency profile of motorcycles and another vehicle (cars). Develop operating speed profile, 85th percentile of motorcycles and other vehicle (cars) for developed of tangents and curves by using speed parameter and geometric parameter. The design consistency prediction models are based on two independents, which is normalized area bounded and standard deviation of operating speeds. There is several km along the segment that has a high ranking based on police accident. From the consistency prediction models, can calculate integrated design consistency route FT 050 of motorcycles and other vehicle (cars) are good consistency. This shows that although the accident collision occurred between other vehicle (cars) and motorcycles, road design consistency is still in good consistency. Factors which may occur are due to the access point on each road on the route F0050, besides the speed of each vehicle. Combining the results on the road consistency with accidents frequency along the sections, it is expecting to produce the relationships between accidents frequency and road design consistency. For the future research, it is recommended to select more study site selection for further analysis and modeling based on road design consistency.

The use of continuous speed profile is to develop an integrated design consistency profile of motorcycles and cars by developing 85th percentile operating speed model for motorcycle and cars. Therefore, the relationship between road accident and integrated road design consistency was described by using the Poisson regression model. For each variable, the parameter was interpreted in terms of the number of road accidents that included of fatality, serious injury and slight injury. Based on the parameter, relationship of the number of road accidents, shoulder width and an integrated design consistency model are to know the probability of road accident occurs between two main vehicles on the roads. Based on the results and analysis, the road segments with high number of access points, improper of shoulder width and lane width are found to be at hazardous road and the chance probability of high road accident prediction between motorcycles and cars occurs is higher. It is indicated that the model development and it was validated for Federal road FT 050 (only). Hence, further study with more Federal roads may necessary.

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