FORECASTING SEVERITY OF TRAFFIC ACCIDENTS USING ROAD GEOMETRY EXTRACTED FROM MOBILE LASER SCANNING DATA

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ABSTRACT

This study analyzed the effects of road geometric elements such as horizontal curvature, superelevation, grade change, and design speed on accident severity. A semi-automatic method is proposed to extract aforementioned geometric elements from mobile laser scanning point clouds. Then a logistic regression model is used to establish relationships between road geometric elements and accident severity. Based on the coefficients calculated by the logistic regression model, the effects of each road geometric element on accident severity are discussed. Results showed that the average superelevation was the most contributed factor to serious injuries, grade change factor was the most critical factor for minor injuries and the damage only of accident severity levels. The analysis revealed that improving superelevations on horizontal curves should be considered by the safety agencies in Malaysia. In addition, design of vertical curves of expressways is also should be imp-roved.

KEYWORDS: road geometry, mobile laser scanner, LiDAR, logistic regression, remote sensing, GIS

1. INTRODUCTION

Ensuring safety on urban expressways is highly important because they play a vital role during peak-hour traffic in most cities worldwide. Information on traffic accidents and on the relevant factors that affect them is significant for traffic safety management related research. Such information is also essential for establishing the relationship between accident severity and relevant explanatory factors. Accident severity can be forecasted using road geometry, road environment, human, and vehicle factors. Although road geometry is not the main cause of traffic accidents. It also can be used to forecast accident severity levels at certain extent (Bahadorimonfared et al., 2013). In addition, establishing relationships between road geometry and accident severity can be helpful in designing more efficient road design standards and can improve the geometry of roads significantly.

Figure 1, Karak Expressway in Malaysia. Also known as Karak Highway is a 60-kilometre (37 mi) controlled-access highway or motorway in Malaysia connecting the capital city of Kuala Lumpur to the town of Karak in Pahang. Photo (a) shows some of the geometric features of the Karak Highway. The highway has risky vertical and horizontal curves. In addition, this highway becomes risky during the rainy days because of the presence of landslides. Photo (b) shows a road accident involving a bus and a trailer truck at KM35.1 of the Karak Highway, near Genting Sempah. The accident occurred on 21 December 2015.

Expressways in Peninsular Malaysia play a vital role during peak-hour traffic by reducing travel time for moderate- to long-distance intra-city trips (Williamson, 2003). These expressways connect major industrial, commercial, and transportation centers; link major seaports and airports. Beside, recent studies have predicted that road accidents will become the fifth leading cause of death worldwide by 2030 (WHO, 2016). In Malaysia, current statistics show that the deaths per 100,000 people are close to 24 for all road users (see Figure 1 which shows some of the critical issues related to traffic accidents in Malaysia). Therefore, many researchers have realized the seriousness of the matter and have conducted an extensive body of research to improve road safety. The most common approach in studying explanatory factors associated with various traffic entities is by developing Accident Prediction Models (APMs). Such models are significant in emergency planning through site ranking, identifying prone areas and key factors that affect the severity of an accident, and in improving road design by incorporating safety consideration into road designs and standards.

Therefore, this study develops a model for forecasting accident severity on Malaysian expressways using road geometry extracted from mobile laser scanning (MLS) data. A semi-automatic approach is designed to extract road geometric elements such as slope, superelevation, horizontal and vertical curves. Then, a logistic regression model is used to establish relationships between road geometric elements and accident severity. Based on the analysis of marginal effects of model variables, effects of each road geometric element are explained. Based on the results obtained from this study, suggestions are made for better safety management on urban expressways in Malaysia.

2. METHODS

2.1 MLS DATASET

The MLS data were collected along the North–South Expressway (between 221 and 225 km) on October 28, 2015 (Figure 2). These data were obtained using Riegl VZ-2000 mobile scanner and Nikon camera D800 (30 mega pixels) on top of a moving vehicle at a speed of 30–40 km/hr. during data acquisition. To achieve the automatic georeferenced of the point cloud, the scanner was connected with Trimble Geo 7X GPS in differential mode. One scanner was permanently placed on a known station, and another was connected directly to the scanner. Both scanners received real-time correction via an interlink with the Malaysian Ministry of Lands and Survey GPS network. A laptop installed with proprietary operating software *Reacquire MLS* was connected to the scanning system. The laptop permitted the interactive real-time point cloud visualization for on-the-site quality assessment and decision making. The entire system was powered by an external source using a 12-volt car battery.

Figure 2. Mobile laser scanning point clouds collected along the North–South Expressway.

Data collection began with a 5-min initialization process to establish the connectivity of the GPS system with the scanner. The team proceeded with the first pass with a camera oriented at 45° in the horizontal direction, and the mobile platform slowly moved along the road. In general, the rear of a vehicle is considered the 0º point, which progresses counter-clockwise in the horizontal direction to form 360º. Each pass includes both the north and south bounds. To allow adequate overlap, the camera orientation was changed to 135°, 315°, and 225° for the second, third, and fourth passes, respectively. At the end of each pass, scanning was stopped to automatically save the scans, stop unnecessary data collection, and save battery life. At the end of the scanning process, a closing 5-min initialization was carried out at the base station. The outcome of the scanning operation resulted in approximately 139.54 million points with a minimum and maximum elevation of 22.32 and 157.06 m, respectively.

2.2 EXTRACTION OF ROAD GEOMETRIC ELEMENTS

Road geometric elements were semi-automatically extracted in five steps (Figure 3). In the first step, the MLS point clouds were used to create a new project in Autodesk ReCap 2016 (Cox, 2015). Point clouds were automatically mosaicked based on their coordinates and the project was saved for further processing in Civil 3D software. In the second step, the point clouds were used to generate a 3D surface presented in contour lines. After that, in third step, two alignments were manually digitized for accurate extraction of geometric parameters. The first alignment was digitized on the south bound of the expressway, whereas the second alignment was generated for the north bound of the expressway. These alignments were then used to produce the surface profiles at a regular interval of 100 meter. The surface profiles allow to calculate the grade changes, K values of vertical curves, and they are essential information to construct cross-sections. In the last step, cross sections were constructed based on the generated surface profiles and the alignments. Road alignments, surface profiles, and cross- sections were then used to prepare the input variables for logistic regression model.

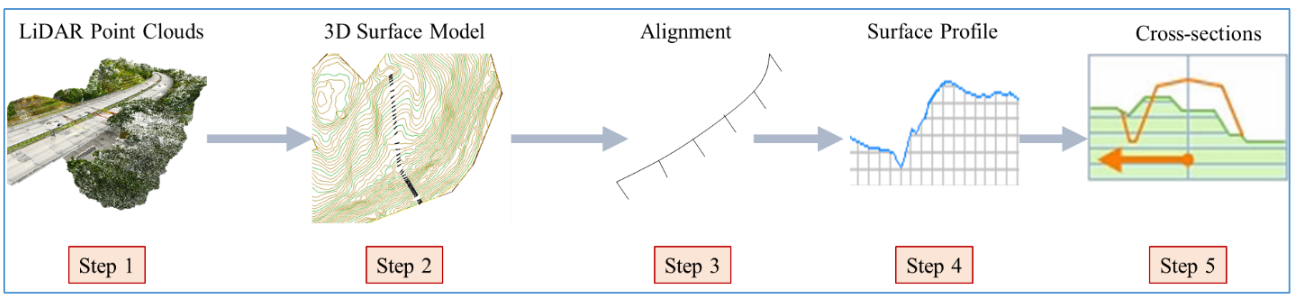

Figure 3. A semi-automatic workflow designed to extract geometric elements of expressways from MLS point clouds for accident severity modelling.

Five variables were calculated and prepared for modelling: horizontal curvature, superelevation, K value of vertical curves, grade change, and design speed. Horizontal curvature was calculated from road alignments using polynomial curve fitting. Superelevations were calculated from cross-sections. K value of vertical curves were calculated using the formulae presented in Equation 1.

$$K = \frac{A}{L} \tag{1}$$

where K is the horizontal distance in meters needed to make 1% change in gradient, A is the algebraic difference in grades ($A = G2 - G1$, where G1 and G2 are the grades of a vertical curve), and L is the length of vertical curve.

In addition, grade changes were estimated from the vertical curves that fitted using parabolic curve fitting method. On the other hand, design speeds were calculated from the horizontal curvatures and superelevation according to the formula presented in Equation 2.

$$\frac{V^2}{15R} = 0.01e + f \tag{2}$$

where R is the radius defined to the vehicles traveled path in ft., V is the design speed (mph), e is the rate of superelevation(percent), and f is the side friction factor (demand factor).

2.3 LOGISTIC REGRESSION MODEL

The logistic regression model is a widely used mathematical technique to establish the relationship between explanatory factors and various types of targets such as accident severity (Bai et al., 2010; Das et al., 2010; Oh et al., 2010). For some application, studies have compared the logistic regression model with other methods and have found logistic regression to be the most accurate of these techniques (Xu et al., 2012). Therefore, a forward stepwise logistic-regression model is applied to establish and analyze relationships between road geometry and accident severity. The predicted values range from 0 to 1, and can be defined by the following formulas:

$$y = b_0 + b_1x_1 + b_2x_2 + \cdots + b_nx_n \tag{3}$$

$$p = \frac{e^y}{1 + e^y} \tag{4}$$

where y is the linear logistic model, b_0 is the intercept of the model, n is the number of road geometric elements (5), b is the weight of each factor, x represents the road geometric elements and P is the probability of accident severity (accident severity index).

3. RESULTS AND DISCUSSION

In the current study, a logistic regression model was developed to establish relationships between five road geometric elements and accident severity of a 5 km stretch from the North–South Expressway in Malaysia. The stretch was segmented into 10 homogeneous sections so that geometric characteristics of the road could be correlated with accident severity. Table 1 and Table 2 show the geometric elements extracted from MLS point clouds based on the method described in Section 2.2. Horizontal curvature, average superelevation, K value, grade change, and design speed of each road section was calculated. The minimum and maximum length of road sections were 200.01 m and 999.83 m, respectively. The calculated horizontal curvatures ranged from 1371.89 m to 32,831.75 m. In addition, the average superelevation of the south and north bounds were 1.58 and 2.19 percent, respectively. The calculated K values and grade changes for the south and north bounds were almost similar as shown in Table 1 and Table 2. On the other hand, the calculated design speeds were ranged from 124.59 km/hr. to 158.87 km/hr. for the south bound and ranged from 127.38 km/hr. to 160.58 km/hr. for the north bound.

Table 1. Road geometric elements of the south bound of the studied stretch of NSE expressway.

Section	Length	Horizontal Curvature	Average Superelevation	K Value	Grade Change (%)	Speed Design	Accident Frequency
1	299.97	5179.05	1.563	113.19	-2.65	147.53	15
2	299.98	1504.79	2.333	122.94	-2.44	126.86	7
3	200.01	1371.89	2.344	115.61	-1.73	124.59	8
4	700.01	1509.17	2.482	7446.91	0.09	127.37	14
5	799.86	32831.75	1.242	569.70	1.40	158.87	40
6	300	9835.21	0.979	175.43	1.71	151.73	5
7	500.04	4753.82	1.275	273.24	1.83	145.27	24
8	999.83	2572.03	1.463	162.57	-6.15	135.89	21
9	399.97	25882.57	1.078	209.40	1.91	157.39	14
10	499.93	10788.75	0.938	267.34	1.87	152.26	14

Table 2. Road geometric elements of the north bound of the studied stretch of NSE expressway.

Section	Length	Horizontal Curvature	Average Superelevation	K Value	Grade Change (%)	Speed Design	Accident Frequency
1	299.97	5179.05	2.542	113.19	-2.65	151.36	16
2	299.98	1504.79	3.389	122.94	-2.44	129.92	13
3	200.01	1371.89	3.333	115.61	-1.73	127.38	12
4	700.01	1509.17	3.262	7446.91	0.09	129.63	32
5	799.86	32831.75	1.615	569.70	1.40	160.58	31
6	300	9835.21	1.306	175.43	1.71	153.13	8
7	500.04	4753.82	1.900	273.24	1.83	147.69	22
8	999.83	2572.03	1.875	162.57	-6.15	137.30	38
9	399.97	25882.57	1.333	209.40	1.91	158.55	9
10	499.93	10788.75	1.396	267.34	1.87	154.23	11

Once the road geometric elements were calculated and prepared in excel sheets, a logistic regression model was applied to estimate the effects on each road geometric elements on the accident severity. Table 3 shows the average estimated effects of each road geometric elements on accident severity. On the other hand, Figure 4 shows the graphical representation of the estimated effects of each road geometric elements.

Table 3. Estimated effects of each road geometric elements on accident severity. These effects were estimated by the logistic regression model.

Variable	Serious	Minor	Damage
Horizontal curvature	0.0006	-0.0005	0.0005
Average superelevation	6.9145	4.258	-12.6233
K value	-0.0013	0.0011	-0.0002
Grade change	-1.8176	3.5204	3.2941
Design speed	0.9691	-0.4739	0.3487

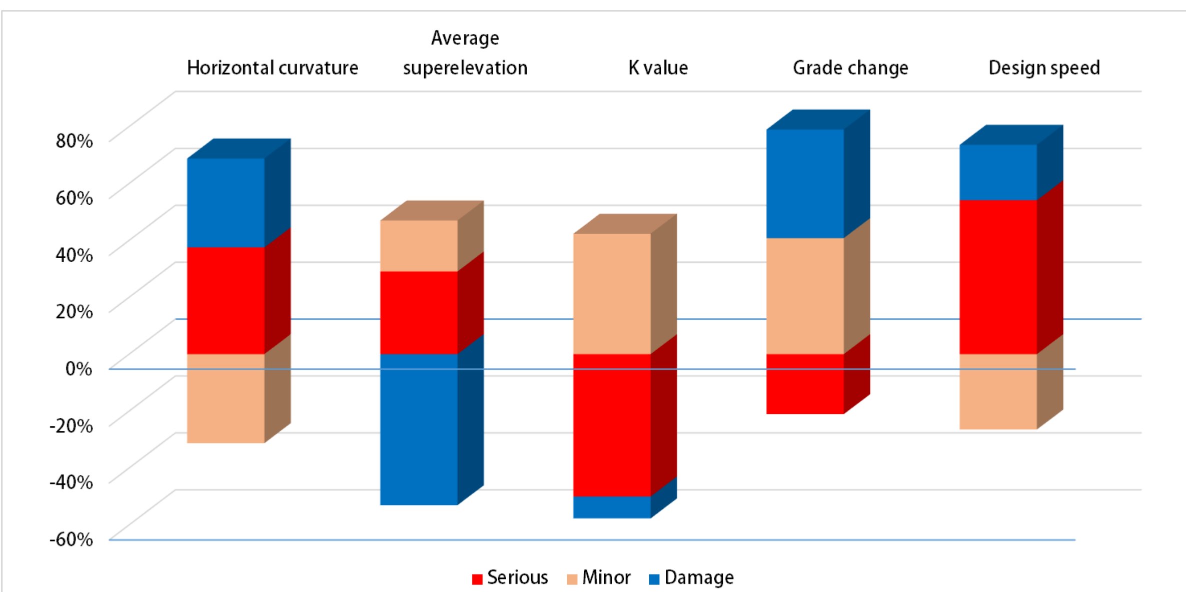

Figure 4. A graph presents the effects of each road geometric elements on accident severity. The effects are normalized.

The graph in Figure 4 shows that the horizontal curvature contributing to increase damages in accidents, while reduces the minor injuries. In curved roads where the horizontal curvature is large, the driver may face challenges to control the vehicle and thereby significant damages to the vehicle is expected. In addition, serious injuries are also expected at horizontal curves because the driver most probability make accidents with other vehicles as he/she may not see the coming vehicles due to the presence of obstacles. In addition, the analysis shows that the average superelevation is responsible to minor injuries more than serious injuries and damages from accidents. Superelevation affect the side friction in a curve, which possible to increase accident risk. The K value was found to mostly contribute to increase minor injuries while reducing the vehicle damages. On the other hand, the logistic regression model indicates that the grade changes increase the vehicle damages and reduces the serious injuries. Furthermore, design speed was found to be a significant factor contributing to serious injuries and vehicle damages as well. The higher the travel speed increases the risk of serious injury or death in a crash. Therefore, improvements in speed limits, car designs, education systems are important to reduce serious injuries of traffic accidents.

CONCLUSION AND FUTURE WORKS

The aim of this study was to extract the main road geometric elements (i.e. horizontal curvature, superelevation, grade change, K value, and design speed) from MLS point clouds. Historical accident records were collected to analyze the effect of road geometric elements on the severity level of the accidents. In general, the analysis showed that the geometric design is within the JKR standards and consistent. In order to carry out the forensic analysis, the most critical area based on the horizontal curves, vertical curves and the number of accidents occurred was identified. Then, the complete road geometry was extracted using a semi-automatic method proposed in the current study. The severity analysis showed that the average superelevation was the most contributed factor to their serious injury, grade change factor was the most critical factor for minor injury and the damage only of accident severity level. Therefore, improving superelevations on horizontal curves is suggested for safety agencies in Malaysia. In addition, improving the design of vertical curves of expressways is also should be highly considered in future.

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