Determining Vehicle Speed at the Entrance of a Traffic Calmed Street Using Linear Mixed Effect Models

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Abstract: Vehicle speed at the residential gateway must be influenced by several factors. Noticeably, a car having lower speed at neighborhood entry maintain that speed up to a certain distance along the road and makes the road calmer. Therefore, it is important to control the entry speed of a vehicle. The present study is designed to establish a relationship between the entry speed and the street features using multiple linear regression analysis. Speed data were collected from 10 different residential roads in Japan. The results showed that the presence of intersection and crossing had a significant influence on entry speed. Furthermore, a mixed effect model has been developed to explain the random behavior of a vehicle considering crossing and intersection as a random variable which cannot be explained by regression analysis alone. The findings are applicable to control the entry speed of a traffic calmed street and make a safer neighborhood.

Keywords: Entry Speed, Traffic Calmed Streets, Geometric Features, Regression Analysis, Mixed Effect Model

1. INTRODUCTION

Speed has been reported as a key factor associated with injuries and crashes not only on highways but also on urban roads as well as on residential roads (Bachok *et al*., 2016). Inappropriate speed (not suitable for the prevailing road conditions) (Schueller, 2011) and excess speed (exceeding the speed limit) both are responsible for road crashes. The risk of a crash involving injury becomes 3% higher and that for fatalities increases 4-5%, if the mean speed of car increases by 1km/h from the posted speed limit (World report on road traffic injury prevention, 2004). According to National Highway Traffic Safety Administration, 2007; among all the fatal crashes, about 31% were caused due to excessive speed in highways (Islam and El-Basyouny, 2013). Conversely, a study in Japan showed that traffic accidents increased to 22.3% in urban residential streets having a 30 km/h speed limit (IATSS, 2007). These data indicated that speed is a risky factor for almost all kinds of the road either the speed limit has set up for 80 km/h in highways or 50 to 40 km/h in urban roads or 30 km/h in a residential road and so on.

A safe environment can be made by controlling the excess speed on residential roads. Residential streets can be classified as a collector road which is mainly connected with the urban roads and having a posted speed limit of 30 km/h (Dinh and Kubota, 2013). Several traffic calming measures both enforcement (30km/h speed limit) and engineering measures such as speed humps, chicanes, etc. have been implemented in residential areas (Lee *et al*., 2013) to overcome the speeding issues. Among the different measures, speed hump is well documented as the most effective traffic calming measure in speed reduction (Rahman *et al*., 2009).

However, it is difficult to maintain a lower speed along the entire length of the road by installing a hump only. Previous research proved that speed on a residential road is strongly influenced by different road geometric factors associated with the surrounding environment of that road (Rahman *et al*., 2017). Numerous speed models have been established in a study by Rahman *et al*., 2019; to predict a lower speed along traffic calmed streets considering the road features. A limitation of this study was, the speed at the entrance of the residential area was higher than the posted speed limit. The speed of an individual vehicle along the neighborhood street is consistent with the entry speed of that road. It can be expected that a car having a lower speed at the residential gateway can maintain that speed up to a certain distance i.e., up to 10m or 15m along through the road (Zainuddin *et al*., 2014). Therefore, it should be an important concern for the urban planner to control the entry speed.

Nevertheless, the safety issues related to speed might be generated at the neighborhood entrances due to the quickly entering tendency of cars and space limitation between cars and people which cannot be ignored. Here the entrance is considered as the connecting point of residential areas and urban roads (Duan *et al*., 2013). There is no statistical evidence about accidents that occurred at the entrance point of residential roads. However, the landscape pattern of the neighborhood (e.g., no separating lane for pedestrians, approaching road of different categories, different shops, and green belt, heterogeneous building structures, obstacle views, etc.) influenced drivers for speeding up and does arise the safety problems (Duan *et al*., 2013). Therefore, the speeding problems at the residential entrance are worthy of ample attention to make the neighborhood much safer and livable.

Based on the issues discussed earlier, the specific objectives of this research are as follows:

- To identify the road geometric factors associated with the speed at the entrance of a residential road.
- To develop a statistical relationship between the entry speed and roadside characteristics using regression equations.
- To explain the random speeding behavior of a vehicle at the gateway considering random factors in a mixed effect model.

2. DATA DESCRIPTION

Individual cars speed data were measured from 10 different residential streets in Japan where a single speed hump is present considering free-flow conditions. The selected roads were located in four different prefectures of Japan e.g., Tokyo, Saitama, Kanagawa, and Okinawa. From Tokyo Prefecture, two roads in Bunkyo were chosen, similarly from Saitama total of four roads (Asaka, Kita-Ageo, Miyoshi, and Tsurugashima), from Kanagawa two roads (Okurayama and Nakayama) and Okinawa, another two roads (Urasoe and Nakanishi) were selected for this study. For collecting speed data STALKER ATS radar gun was used along with a Speedometer. The speed at the starting point of the survey was considered as the entry speed for the present study.

2.1 Study Sites

The traffic calmed street where a single speed hump is present and the speed limit is 30km/h has been selected as the survey location for the current study. The selected roads are classified as residential roads which are connected with an urban road either on both sides or on one side. The study locations were chosen for this study consist of different landscape patterns. For example, the roads selected in Saitama prefecture have residential areas along one side or both sides of the road together with embankment or agricultural fields. Alternatively, the locations in Okinawa, Kanagawa, and Tokyo prefecture were chosen considering the presence of the elementary school and railway station very close to the selected road to investigate the speed behavior in such kind of busy roads. The street sections were also selected based on the existence of pedestrian crossing, intersection, etc. at the approaching point of a neighborhood street to better understand the entry speed behavior.

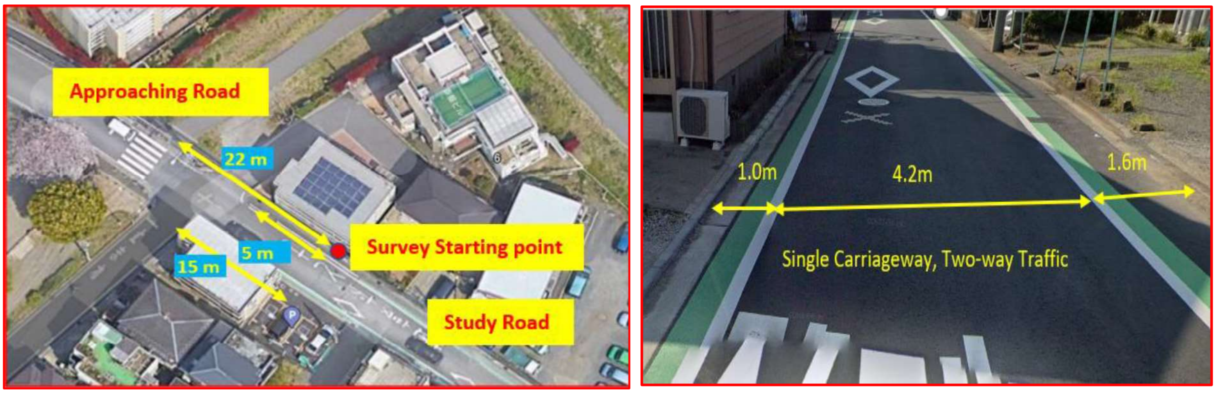

Figure 1. A typical picture of a residential gateway

2.2 Selected Street Features

The standard geometric features that are commonly found in almost every entrance of a residential street (Shahram *et al.*, 2014; Dinh *et al.*, 2013) were considered as independent variables for developing a speed model. Detail descriptions of the selected road characteristics are summarized in Table 1.

Table 1. Summary of selected street section features

Characteristics	Measured value
Length of Street Section (m)	150 to 313; mean: 197.4
Carriageway Width (m) of study road	Width range is between 2.75m to 5m: 9 sites (considered as single lane road) Width is 6.63m: 1 site (considered as a two-lane road)
The Direction of Traffic in study road	Two-way: 8 sites One-way: 2 sites
Approaching Road Condition	Carriageway Width range is between 3m to 5m, single lane, and two-way traffic: 7 sites Carriageway Width is more than 5m, multi-lane, and two-way traffic: 3 sites
Presence of Crossing	Within 0 m to 15 m distance from the survey starting point or the road entrance: 1 site Within 16 m to 30 m distance from the survey starting point or the road entrance: 2 sites

Table 1. Summary of selected street section features

Characteristics	Measured value
Presence of Intersection	Within 0 m to 20 m distance from the survey starting point or the road entrance: 4 sites Within 21 m to 40 m distance from the survey starting point or the road entrance: 1 site

2.3 Speed Survey

Using a STALKER ATS radar gun connected to a laptop, speed data were recorded. Three surveyors were involved in field data collection. Among them, Surveyor 1 operated a radar gun, Surveyor 2 recorded the speed data on a laptop, and Surveyor 3 was involved in collecting the spot speed data using a speedometer at the starting point of the survey. The data from Surveyors 2 and 3 were rechecked later to ensure the exact entry speed. Speed data were measured about 5m distance from the entrance of the road to avoid the unfavorable situations that may occur with drivers in the site; the gun and surveyors were always hidden and radar gun was set up on the same side of the study lane to maintain the accuracy of speed data.

A total of three video cameras were installed during survey time and the free flow movement of the vehicles was certified using the video recording later in the laboratory. Furthermore, a cut-off speed of 9 km/h was set up for the radar gun for some locations with high interference. It indicated that if the target vehicle interrupted by any other moving objects like pedestrian or cyclists having speed less than the cut-off values were eliminated from the final data set. Minimum 20 profile speeds were collected for each study site to fulfill the statistical analysis criteria; the maximum was 97 and the average speed count was 57. Data were collected during the daytime only in good weather conditions.

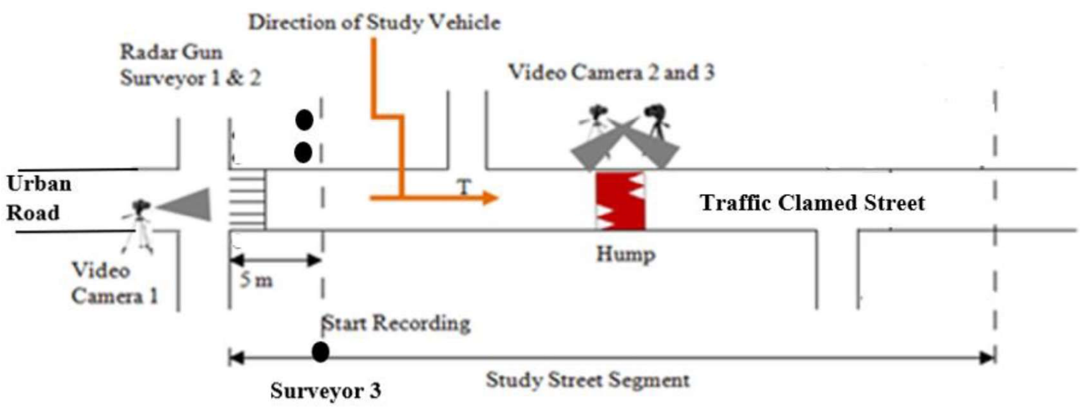

Figure 2. Field data collection

3. DATA ANALYSIS

3.1 Analysis of Variance of Vehicle Speed Based on Crossing or Intersection Present at The Entrance of Road

Two types of analysis of variance (ANOVA) of car speed have been done in Table 2; to identify that whether the speed at the entrance of a road has a significant difference if pedestrian crossing and intersection is present at the road entrance or not. From the table, it can be seen that the variation between groups is enough big compared to variation within groups. ANOVA

1 indicated that there is a significant difference between the entry speed of a vehicle on a road where pedestrian crossing is present or not. Similarly, ANOVA 2 represents the effect of the existence of any intersection at the road gateway on car speed. Therefore, further analysis is needed to realize the entry speed characteristics of a traffic calmed street considering the presence of crossing or intersection at the approaching point.

Table 2. ANOVA of speed with and without crossing or intersection at the entry of road

Test	Variable	Sample Size	Mean	Standard Deviation	p-value	F Critical
ANOVA 1	With Crossing	160	32.95	9.24	0.002*	3.86
	Without Crossing	253	35.67	7.89		
ANOVA 2	With Intersection	268	27.53	9.33	0.000**	3.85
	Without Intersection	303	32.97	7.59		

Note: $*p<0.05$, $**p<0.0001$

3.2 Model Development

3.2.1 Multiple linear regression

Based on the ANOVA analysis shown in Table 2; the current study employing Multiple Linear Regression analysis to estimate the car speed at the entry point of a traffic calmed street. A limited number of road geometric factors which are associated with the entry speed of a road were considered for speed estimation in this study. The general form of Multiple Linear Regression is shown in Equation (1):

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots\ldots + \beta_k x_k + \varepsilon \quad (1)$$

where, Y is the dependent variable; $x_1, x_2, x_3 \ldots x_n$ are the independent predictor variables; $\beta_0, \beta_1, \beta_2 \ldots \beta_k$ are unknown regression coefficients and ε is the random error.

In the present study, the logarithmic form of the dependent variable has been taken to reduce “heteroscedasticity as well as to create a linear relationship between the dependent and independent variables. The model form is as follows:

$$ln\ Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots\ldots + \beta_k x_k + \varepsilon \quad (2)$$

wherein,

Y = vehicle speed at the starting point of survey (V_i km/h),
x_1, x_2 = vectors of independent variables representing street features,
β_0 = estimable parameter (constants),
ε = disturbance terms, and
β_1, β_2 = estimable parameters (Coefficients of independent variables to be calculated)

Two types of inspection have been done to check that either the data used in the developed models are error-free and best fitted for the regression model or not. In the first test, the suitable data were screened by developing several models where the relationships between the independent variables and each dependent variable were confirmed by using scatter plots. Whereas, in the second test all the assumptions for multiple linear regression have been checked including multicollinearity test (considering variance inflation factor VIF<5.0), homoscedasticity, normally distributed errors, and error independence. Finally, the independent variables having a 95% level of significance were selected for the final speed models. In this analysis, both continuous forms and categorical forms were considered for every independent variable.

For a better understanding of the entry speed at the study road, the speed model at the starting point of the survey location was derived by multiple linear regression analysis.

3.2.1.1 Dependent variable

A total of ten locations where a single speed hump is present were selected for this study to calculate the speed of a vehicle at the entrance of that road. Speed data were measured at a distance of about 5m from the starting point of the selected road and considered as dependent variables for analysis. Table 3 represents the descriptive statistics of the dependent variables.

Table 3 Descriptive statistics of dependent variables

Variable V_i	N	Min. speed	Max. speed	Mean speed	Standard Error Mean	Standard Deviation	Skewness	Kurtosis
V_i (km/h)	570	9.01	58.0	30.42	0.45	9.64	-0.04	-0.58

Note: "V_i" indicates the speed at a 5m distance from the starting point of the study road

From Table 3, it has been found that the values of the skewness and kurtosis for dependent variables were near zero. This showed that the data were normally distributed (Zainuddin *et al*., 2013).

3.2.1.2 Speed estimation model

The geometric roadway and roadside characteristics which are closely related to the speed at the entrance of a road have been considered as independent variables in this study e.g., length of study street section, carriageway width of the approaching road, the presence of the pedestrian crossing, and intersection within a certain distance from the survey road. Table 4 represents the regression analysis results for estimating the speed at the entrance of a traffic calmed street.

Table 4. Speed estimating models at the entrance of traffic calmed street

Variable	Estimated Coefficient	t-ratio	sig	Adj R^2	Sample Size
Dependent Variable: Logarithm of speed at a certain distance from the starting of survey road					
Constant	2.759	46.571	0.000*		
Carriageway width of approaching road (1 = width range is 3m to 5m, 0 = otherwise)	0.141	12.079	0.000*		
Crossing present within 0m to 15m distance from the survey starting point (1 = yes, 0 = otherwise)	0.923	20.555	0.000*	0.528	570
Crossing present within 16m to 30m distance from the survey starting point (1 = yes, 0 = otherwise)	0.250	5.071	0.000*		

Table 4. Speed estimating models at the entrance of traffic calmed street

Variable	Estimated Coefficient	t-ratio	sig	Adj R^2	Sample Size
Dependent Variable: Logarithm of speed at a certain distance from the starting of survey road					
Intersection present within 0m to 20m distance from the survey starting point (1 = yes, 0 = otherwise)	-0.482	-11.884	0.000*	0.528	570
Intersection present within 21m to 40m distance from the survey starting point (1 = yes, 0 = otherwise)	-0.355	-7.512	0.000*		

Note: *p<0.0001

3.2.1.3 Validity check of regression model

The current study checks the validity of the developed regression model described in table 4, by conducting several statistical tests. Goodness-of-fit tests, such as the Shapiro-Wilk test, are used to assess whether the residuals are distributed normally or not (Park, 2008). To check the homoscedasticity and autocorrelation among the residuals, the Breusch-Pagan test (Econometrics, Chapter 8, Heteroskedasticity) and Durbin-Watson value have been checked. Finally, the analysis of variance (ANOVA) is conducted to find out the value of the F-test.

Table 5. Validity check of the developed regression model

Statistical Test	Value
Shapiro-Wilk	0.092*
Breusch-Pagan test	0.104*
Durbin-Watson	1.92
F-test	128.147**

Note: *p-value>0.05, **p- value<0.0001

From Table 5, it has been found that the value of the Shapiro-Wilk and Breusch-Pagan test was greater than the p-value (0.05), the value of Durbin-Watson is about 1.92 which is close to standard value 2 and the p-value for the developed regression model is significant. Hence the regression model is significant and could be used to predict the speed at the entrance of a traffic calmed road.

3.2.2 Linear mixed model

The entry speed at the ten different locations under the existence of various road geometric features near the road entry was calculated. Noticeably, the speed data of an individual vehicle when it accesses a residential road from an urban road; influenced by the surrounding landscape of that location or the existing road geometry. Such inducing factors may be either the carriageway width (C) of the approaching road or any pedestrian crossing which is present within a 15m (PC15) or 30m (PC30) distance from the survey starting point or the road entrance or any 3-leg or 4-leg intersection at 20m (I20) or 40m (I40) distance from the survey starting point or the road entrance. But the relationship between such types of variables with speed is highly unbalanced. The speed might be increase or decrease due to the geometric features which are already estimated in the regression model (Table 4). However, the variability of the fitted regression coefficients separately for each factor can be difficult to interpret because; the activities of road users on road as well as on pedestrian crossing are unpredictable. The regression analysis cannot define such kinds of events separately (Mao *et al*., 2016). Therefore, a more rigorous statistical analysis requires a mixed effect model, where certain regression coefficients are regarded as random effects (parameters).

The data were further analyzed using the linear mixed model approach for getting a fixed effect for the random parameters. Statistical analyses were performed using SPSS version 23.0, and the level of significance was set at P<0.05. Speed data at the entrance of a neighborhood street considered as the dependent variable for the Linear Mixed Model (LMM) where the carriageway width (C) of approaching road has been considered as a fixed factor and presence of crossing or intersection at a different distance (PC15, PC30, I20, I40) has been considered as a random factor. LMM encompassed all models on the unstructured covariance procedure and based on the maximum likelihood (ML) method.

3.2.2.1 Model development

Several mixed models were developed in the current study based on the statistically significant value of the variables (P<0.05). The data was restructured based on the repeated measures of carriageway width of the approaching road in the ten different locations. The best-fitted model was selected based on the three indicators, such as Akaike's information criterion (AIC), residuals, and Interclass correlation coefficient (ICC) values. Generally, the smaller of AIC and residual values, the better the model fit to data (A technical report on SPSS). Moreover, the higher ICC values mean more random intercept concerning the residuals, higher contributions of fixed and random effects. The LMM was considered carriageway width as a fixed factor and the presence of pedestrian crossing or intersection at a certain distance from the entrance of a road as random factors. The relation between fixed and random factors with the dependent variable is shown in equation (3):

$$Y_i = C_j + PC15_k + PC30_k + I20_l + I40_l + CPC15_{jk} + CPC30_{jk} + CI20_{jl} + CI40_{jl} + I20PC15_{kl} + I20PC30_{kl} + I40PC15_{jkl} + I40PC30_{kl} + PC15(C_j)I20_{kl} + PC30(C_j)I20_{kl} + PC15(C_j)I40_{kl} + PC30(C_j)I40_{kl} \quad (3)$$

Where; Y_i is the speed of a vehicle at the i-th distance (i = 5m distance from the road entry to the starting point of the survey) considering a different combination of road geometry at the j-th width (j = 3m, 4m, 5m, 6.5m), k-th distance (k = 15m, 30m) and l-th distance (l = 20m, 40m), C_j is fixed factor of the j-th carriageway width; $PC15_k$ and $PC30_k$ denote the random effect of a vehicle's speed if a crossing is present within 0 to 15m or 16 to 30m distance from the survey starting point or the gateway of a traffic calmed road respectively; $I20_l$ and $I40_l$ represent the random effect of the vehicle's speed if a major or minor intersection is present within 0 to 20m or 21 to 40m distance from the survey starting point or the entrance of a road respectively.

Hierarchical grouping from equation (3) was made based on the statistically significant (P<0.05) values to optimize an objective function. The model was started based on the random intercept model and later including fixed intercept, random intercept, and slope as follows:

Model 1: $Y_i = \beta_0 + \gamma_0 + r_i$

Model 2: $Y_{ij} = \beta_0 + \beta_j C_j + \gamma_0 + r_{ij}$

Model 3: $Y_{ijk} = \beta_0 + \beta_j C_j + \gamma_k PC30_k + \gamma_0 + r_{ijk}$

Model 4: $Y_{ijl} = \beta_0 + \beta_j C_j + \gamma_l I40_l + \gamma_0 + r_{ijl}$

Model 5: $Y_{ijkl} = \beta_0 + \beta_j C_j + \gamma_k PC15_k + \gamma_l I40_l + \gamma_0 + r_{ijkl}$

Model 6: $Y_{ijkl} = \beta_0 + \beta_j C_j + \gamma_k PC30_k + \gamma_l I40_l + \gamma_0 + r_{ijkl}$

Model 7: $Y_{ijkl} = \beta_0 + \beta_j C_j + \gamma_k PC15_k + \gamma_k PC30_k + \gamma_l I20_l + \gamma_l I40_l + \gamma_0 + r_{ijkl}$

Model 8: $Y_{ijk} = \beta_0 + \beta_j C_j + \gamma_i CPC15_{jk} + \gamma_0 + r_{ijk}$

Model 9: $Y_{ijl} = \beta_0 + \beta_j C_j + \gamma_i CI20_{jl} + \gamma_0 + r_{ijl}$

Model 10: $Y_{ijkl} = \beta_0 + \beta_j C_j + \gamma_i PC15(C_j)I40_{kl} + \gamma_0 + r_{ijkl}$

Where; β_0 is the coefficient of intercept of fixed effect; β_j is the fixed effect coefficients; γ_k and γ_l are the random effect coefficients; γ_0 is the intercept of random effect representing between-subjects variation; r is the residual of the model.

3.2.2.2 LMM estimation

LMM explored the factors affecting the entry speed (Y_i) considering different features in the different models based on the statistically significant fixed effect parameters and individual covariance parameters. For the longitudinal data, the unstructured covariance model often offers the best fit model and requires no assumption in the error structure (Shek and Ma, 2011). These models counted the lowest value of residual as well as AIC for the best-fitted model. A total of ten models were developed to understand the effects of fixed and random factors properly. The detailed estimation is summarized as follows:

Table 6. Summarize the LMM model coefficient of variables

Model	AIC	β_0	β_j (C = 3, 4, 5)	γ_0	γ	r	ICC
Model 1	4317.317	30.76	-	4.11	-	109.124	0.03
Model 2	4185.934	35.45	(-3.26, -11.48, -0.438)	-	-	88.66	0.61
Model 3	4198.059	35.45	(-3.26, -11.45, -0.438)	-	150.65	96.77	0.59
Model 4	4172.134	35.62	(-3.21, -11.30, 2.37)	-	119.42	82.74	0.77
Model 5	4388.894	39.06	(-9.07, -9.74, 3.38)	-	100.276	69.13	0.78
Model 6	4520.890	35.08	(-2.71, -10.24, 3.23)	-	117.38	32.9	0.82
Model 7	4470.774	39.21	(-9.35, -7.63, 3.52)	-	123.56	35.01	0.79
Model 8	4281.234	34.37	(-0.135, -7.56, 2.59)	-	173.89	44.33	0.79
Model 9	**4247.539**	**34.49**	**(-0.157, -6.83, 2.61)**	**-**	**234.54**	**31.89**	**0.88**
Model 10	4265.722	33.69	(0.9, -6.37, 3.79)	-	187.23	43.07	0.81

Note: Bold color represents the best-fitted model

4. MODEL INTERPRETATIONS AND DISCUSSIONS

Brief interpretations about the results for regression model and mixed models are discussed below:

4.1 Regression Model

The developed model in Table 4 indicated that on neighborhood streets with a 30 km/h speed limit where a single speed hump is present, the entry speeds of cars are associated with various road geometric features. Detailed explanations of the results are discussed in this section.

4.1.1 Speed model at the entrance of study locations

The approaching road of a traffic calmed street having a carriageway width ranging from 3m to 5m was considered as an independent variable in the regression analysis. Among the 10 different locations, the approaching road condition in 7 sites is similar to the study road i.e., carriageway width, number of lanes, and traffic direction are the same. From the regression analysis, it can be seen that the vehicle speed at the entering of a traffic calmed street (Vi km/h) is positively associated with the carriageway width. It indicated that if the approaching road of a traffic calmed street is a single lane and the carriageway width is within a range of 3m to 5m, speed will be increased by 1.36 km/h at the entrance of the target road. The positive effect of carriageway width is consistent with the findings of Yaacob and Hamsa, 2013.

Moreover, the result also revealed that the presence of crossing at a certain distance from the traffic calmed street gateway influenced the entry speed of that road positively. The possible explanation for this positive effect is that only the unsignalized crossings were considered in this study; therefore, the vehicle speed might be varied due to the presence or absence of road users on the road. Which is a random event. The result shows that, entry speed increases by 0.923σ or 8.9 km/h in case of the presence of crossing at a distance of 0m to 15m from the starting point of the survey. Whereas entry speed will increase by 0.250σ or 2.41 km/h if a crossing is present within 16m to 30m distance from the entrance. Which is consistent with the findings of Johansson. C. (2011).

In the current study, only the un-signalized 3-leg and 4-leg intersection have been considered. The speed model indicated that the existence of any intersection very close to a neighborhood street can reduce the entry speed of that road. If an intersection present within a distance of 0m to 20m or 21m to 40m from the entrance of the road then vehicle speed will be decreased by 4.65 km/h and 3.42 km/h respectively. The negative effect of these influential factors in the present study is consistent with the findings of Rahman *et al*. (2017).

4.2 LMM Models

Model 1: In the first model only, the dependent variables were inputted in the LMM to understand the speed behavior. The result showed that the value of intercept for the fixed and random effects were about 30.76 and 4.11 respectively. Here, the random effects accounted for the heterogeneity among the subjects by allowing differences from the overall averages. The error was 109.124 for the variation unexplained by the fixed and random effects. Interclass correlation coefficient (ICC) for Model 1 was only 3% [4.11/ (4.11+109.124)] of the total variation in the speed due to interindividual differences. In other words, the estimated average stability of the entry speed was 0.03 which is not significant. Therefore, this model clearly explained that a vehicle's speed must be influenced by other random factors rather than by its own effects.

Model 2: The carriageway width of approaching roads (varies from 3m to 6.5m) of ten selected locations was considered as a fixed factor and entered into the second model along with the dependent variable. The significant values in both the intercept and linear slope parameters indicate that the initial status and linear growth rate of speed for different carriageway widths were not constant. The speed at the entry point of a road decreased by 3.26σ (σ indicates standard deviation), 11.48σ and 0.438σ if the carriageway width changes from 3m, 4m and 5m respectively. The effect of the carriageway having a width of about 6.5m was found as a not significant factor for the entry speed model. Whereas, the random error terms associated with the intercept and linear effect were significant and the value was 88.66. The estimated value of ICC for Model 2 was 61% which is significant.

Model 3: In the third model, a random factor named PC30 (presence of pedestrian crossing within 16m to 30m distance from the entrance of a traffic calmed street) was inputted along with the fixed factor C (carriageway width). Results showed that the value of AIC and residuals increased compared to the previous model (Model 2), whereas the effect of fixed factors remained the same as Model 2. The values of AIC and residuals of this model explained the random behavior of speed due to the existence of crossing near the road entry.

Model 4: Model 4 was developed by considering a new random factor named I40 (presence of a 3-leg or 4-leg intersection within 21m to 40m distance from the entrance of a traffic calmed road) along with the fixed factor C (carriageway width) and the dependent variable. This model explored a new appearance of the fixed factor C. The speed at the entry point of a road decreased by 3.21σ and 11.30σ for the carriageway width 3m and 4m respectively and increased by 2.37σ for a width of 5m. Probably, the reason for this type of variation is the effect of the single lane and two-lane approach of the target road as both the conditions were considered in the LMM model which cannot be expressed by regression analysis. The model output clearly explained that entry speed is positively associated with the carriageway width of approaching road which is also consistent with the findings of the developed regression model in this study.

Model 5: In the 5th model, two random parameters named PC15 (presence of pedestrian crossing within 0m to 15m distance from the entrance of a traffic calmed street) and I40 were entered together along with the same fixed factor mentioned before. This model also showed similar appearances for carriageway width as shown in Model 4 but the coefficients were relatively higher than Model 4. However, the random error terms associated with the intercept and linear effect were found significant in this model and the value was about 69.13 which is lower among the previous models (Model 1 to 4). The estimated average stability of the entry speed for Model 5 was 0.78.

Model 6: Model 6 is almost similar to model 5. Here, PC30 was inputted as a random factor instead of PC15 and the remaining factors were as same as Model 5. The resulting output showed an increasing value of AIC than that of Model 5.

Model 7: In the 7th model, all the random factors (PC15, PC30, I20, and I40) were considered together along with the fixed factor and dependent variable. Here the AIC value showing an increasing trend while the error terms were decreasing. However, all of the factors were found as a significant speed influencing factor.

Model 8: A combined effect of a fixed factor C and a random factor PC15 has been implemented in model 8 to estimate the entry speed. The interaction between these two variables showed a significant result. The speed will be decreased by 0.135σ if the carriageway width of the approaching road is 3m and there is a pedestrian crossing within 15m distance of the target road gateway. This model described the relation between the speed and the random activities of road users clearly.

Model 9: Model 9 also considered the interaction of a fixed factor and a random factor like Model 8. Nevertheless, this model estimated the interaction between carriageway width (C) and an intersection that exists within 20m distance from the road entrance point (I20) instead of PC15. The results showed a lower AIC and residual value compared to Model 8. Therefore, it can be concluded that this model can explain the random behavior of car speed at the access point of a road more precisely than the previous one though the model structure was almost similar and also explain the accuracy of the prediction model developed by the regression equation.

Model 10: In Model 10, a total of three individual factors have been considered together to calculate the speed effects. Among the three factors; one was carriageway width (C) and the other two were PC15 and I20. However, the result showed an opposite relation between speed and carriageway width. The speed will be increased by 0.9σ if the width is 3m which is theoretically inconsistent.

Hypothetically the findings of Model 8 and Model 9 were almost similar; as because both of the models can explain the random behavior of a vehicle in case of lower carriageway width and presence of crossing or intersection near to the road entrance. However, based on the minimum AIC, residuals, and maximum ICC values, it was observed that Model 9 (AIC = 4247.539, residual = 31.89, and ICC = 0.88) fitted the best model criterion.

The most important factor on the LMM model was the availability to specify and compare different model values of the within-individual residual covariance structure. For example; the residual value was 88.66 after considering carriageway width as a fixed effect, and the residual value was turned to 31.89 after adding several random factors such as pedestrian crossing and intersection, etc.; which is not possible to explain through regression analysis. Moreover, in the case of pedestrian crossing present within 0m to 30m distance from the residential gateway; the entry speed showing an increasing trend in the regression model. Alternatively, in mixed effect models (Model 3, 5, 6, 7, 8, and 10) the entry speed varying according to the combination of all factors i.e., carriageway width and crossing. Therefore, to understand the characteristics of entry speed more precisely the combination among all the factors should be considered not the crossing only. For example, among the 10 LMM models; model 8 can be selected to realize the impact of crossing over entry speed which will help practitioners to choose whether the crossing should be placed or not in such platform.

5 CONCLUSIONS AND RECOMMENDATIONS

Previous studies investigated mostly the speed reduction efficiencies of humps and developed numerous models to reduce the speed of an individual car along a traffic calmed street by considering several road geometric factors. However, to make the residential neighborhood safe and secure, it is important to control the speed at the entrance of a residential street. If the entry speed becomes high, it will show an increasing trend of speed along the road even though a hump is installed on that road for speed reduction. Therefore, the speeding behavior of a vehicle at the gateway of a traffic calmed street has been examined in this current study using multiple linear regression analysis and linear mixed model effects. In the regression model different road geometric features e.g., carriageway width of approaching road, presence of pedestrian crossing, or any 3-leg or 4-leg intersection at a certain distance from the road entrance found to be significant variables for vehicle speed prediction at the entry point.

However, the significant road features found in the regression model cannot represent the random behavior of a vehicle in case of the presence of any road user on the crossing or other vehicle's movements at the intersection. It is difficult to explain such types of variability by using a simple regression or a prediction model. Therefore, a detailed analysis was done by using a linear mixed model to explain the speeding behavior considering the regression coefficients as random effects or parameters. A total of 10 models have been developed under the concept of mixed effect; where the carriageway width of the approaching road was selected as a fixed factor and the other factors like pedestrian crossing or intersection were considered as random variables. Different kinds of interactions between the fixed and random factors were found as a significant variable that can explain the random actions of a vehicle at the entrance point of a neighborhood street. Nevertheless, the model (Model 9) showing a lower AIC and residual values with a higher ICC have been considered as the best-fitted model both statically and hypothetically. This model can explain the speeding behavior of a vehicle in case of random events that occur on road (i.e., pedestrian activities on a crossing or other vehicles movement on intersection) more precisely than the prediction model developed in the regression equation. The lower value of the error term finds in Model 9 also described the accuracy of the prediction model.

The models developed in this study are applicable to control the entry speed of a vehicle during entering into a residential street having a 30 km/h speed limit where a single hump is present. And obviously, if the entry speed becomes lower, the speed trajectory of an individual car must be showing a decreasing trend along a certain distance of that road which will help to make the road safer and calmer for the residents. However, the regression model of the current study, considered only the effect of approaching roads having carriageway width similar to the neighborhood street to measure the speed at the entrance of a residential gateway. A wide variety of geometric features at the approaching road (i.e., major intersection, signalized pedestrian crossing, etc.) should be taken into account for further research. Moreover, this study is confined to discuss the influence of several geometric factors on entry speed only, the landscape pattern of the road and driver's attitude toward the entrance is of future research of interest.

REFERENCESf

Bachok, K.S.R., Hamsa, A.A.K., Mohamed, M.Z., Ibrahim, M. (2016) A theoretical overview of road hump effects on traffic speed in residential environments. *Journal of the Malaysian Institute of Planners*, IV (2016), 343-352.

Dinh, D.D., Kubota, H. (2013) Profile-speed data-based models to estimate operating speeds for urban residential streets with a 30 km/h speed limit. *IATSS Research*, 36, 115-122.

Dinh, D.D., Kojima, A., Kubota, H. (2013) Modeling operating speeds on residential streets with a 30 km/h speed limit: regression versus neural networks approach. *Proceedings of the Eastern Asia Society for Transportation Studies*, Vol.9.

Duan, M., Ya, H., Zhang, L., Jia, H. (2013) Traffic safety analysis of intersections between the residential entrance and urban road. *Procedia - Social and Behavioral Sciences*, 96, 1001-1007.

Econometrics, Chapter 8, Heteroskedasticity, Shalabh, IIT Kanpur. (http://home.iitk.ac.in/~shalab/econometrics/Chapter8-Econometrics-Heteroskedasticity.pdf)

International Association of Traffic and Safety Sciences (IATSS) (2007) Statistics 2006, Road Accidents Japan. Traffic Bureau, National Police Agency.

Islam, M. T., El-Basyouny, K. (2013) An integrated speed management plan to reduce vehicle speeds in residential areas: Implementation and evaluation of the Silverberry Action Plan. *Journal of Safety Research,* 45, 85-93.

Johansson, C., Rosander, P., Leden, L. (2011) Distance between speed humps and pedestrian crossings: Does it matter? *Accident Analysis and Prevention,* 43, 1846–1851.

Lee, G., Joo, S., Oh, C., Choi, K. (2013) An evaluation framework for traffic calming measures in residential areas. *Transportation Research Part D*, 25, 68-76.

Linear Mixed-Effects Modeling in SPSS: An Introduction to the MIXED Procedure. A technical report.
Mao, W., Rychlik, I., Wallin, J., Storhaug, G. (2016) Statistical Models for the Speed Prediction of a Container Ship. *Journal of Ocean Engineering*, 126, 152-162.
Park, H. M. (2008) Univariate analysis and normality test using SAS, Stata, and SPSS. Working paper, the Univ. Information Technology Services (UITS) Center for Statistical and Mathematical Computing, Indiana Univ. Retrieved August 30 2011, (http://www.indiana.edu/ ~statmath/stat/all/normality/index.html)
Rahman, F., Kojima, A., Kubota, H. (2009) Investigation on North American traffic Calming device selection practices. *IATSS Research,* 33 (No-2), 105-119.
Rahman, M., Tung, N.H., Kojima, A., Kubota, H. (2017) Identification of external factors affecting the effectiveness of speed humps. *Journal of the Eastern Asia Society for Transportation Studies*, 12, 2016-2034.
Rahman, M., Kojima, A., Kubota, H. (2019) Predicting individual vehicle speed profile of urban residential streets where a single hump is present considering the road geometric features. *Journal of the Eastern Asia Society for Transportation Studies*, 13, 2137-2153.
Schueller, H. (2011) Modeling Speeds and Accidents on Urban Streets. *International Conference on Transportation Information and Safety (ICTIS), ASCE 2011,* 830,-836.
Shahram, H., Luis, F. M., Liping, F. (2014) Speed limit reduction in urban areas: A before-after study using Bayesian generalized mixed linear models. *Accident Analysis and Prevention*, 73, 252-261.
Shek, D. T. L., Ma, C. M. S. (2011) Longitudinal data analyses using linear mixed models in spss: concepts, procedures and illustrations. *The Scientific World Journal,* 11, 42-76.
World report on road traffic injury prevention. World Health Organization 2004. (http://www.who.int/violence_injury_prevention)
Yaacob, N. A., Hamsa, A. A. K. (2013) The effect of road hump in reducing speed of motorcars in a residential area in Kuala Lumpur. *Journal of Design and Built Environment*, 13.
Zainuddin, N.I., Adnan, M.A., Diah, J.M. (2014) Optimization of speed hump geometric design: case study on residential streets in Malaysia. *Journal of Transportation Engineering,* 140 (3), 1943-5436.