Speed Variation of Vehicles Correspondent to Road, Driver, and Environmental Characteristics

Niranga Amarasingha, and Navodi Nisansala Samarasinghe

Published Version Information

Amarasingha, N., Samarasinghe N.N., (2019) Speed Variation of Vehicles Correspondent to Road, Driver, and Environmental Characteristics, proceeding of the 7th International Symposium on Advances in Civil and Environmental Engineering Practices for Sustainable Development (ACEPS), 17 October, Galle, Sri Lanka.

Proceedings of the 7th International Symposium on

Advances in Civil and Environmental Engineering Practices for Sustainable Development

ACEPS - 2019

Speed Variation of Vehicles Correspondent to Road, Driver, and Environmental Characteristics

N. Amarasingha[1], N.N. Samarasinghe[1]

[1]Department of Civil Engineering, Faculty of Engineering, Sri Lanka Institute of Information Technology, Malabe, SRI LANKA

ARTICLE INFO

Article history:
Received 10 September 2019
Revised 02 October 2019
Accepted
Available online

Keywords:
Speed limit variation
Posted speed limit
Multiple regression analysis

ABSTRACT

According to the Sri Lankan Police records, the major problem for road crashes can be pointed out as speeding. Speed limit is one of the most important factors for road users, drivers as well as the pedestrians. Variation of speed limit affect the travel time, comfort, economy, and safety. Operating speed models influence the design of traffic flow network models, road design, design consistency, and traffic safety. This research attempts to identify the parameters which affects for the speed variations of vehicles by selecting curved and straight roadway sections in Colombo-Galle road. The research was conducted at a random sample of 1200 vehicles in five roadway sections on road, driver and environmental characteristics. Two multiple regression models for straight and curved roadways sections were developed. The variable which effect on speed variation were found. This study can be used as a baseline for development of more comprehensive speed variation models for Sri Lankan traffic condition.

1. INTRODUCTION

Speed management and traffic controlling are the most complex challenges for every country. To overcome those matters speed models are developed. Speed models influence the design of traffic flow network models, road design, design consistency, and traffic safety. Most urban traffic network models rely on existing traffic flow data as inputs. However, network models are required to make assumptions regarding vehicle operating speeds. Speed models would also improve network performance. The complete road design approach is moving away from a car centric design by setting the design speed as the posted speed limit, allowing narrower lanes, allowing on street parking, reduced pedestrian crossing distances etc. In such an approach knowing how design elements affect operating speeds will serve better design. At the completion of road designing, the major challenge to control the vehicle speed throughout the road sections with different characteristics.

In accordance of economic growth, the number of vehicle population is increasing in Sri Lanka as shown in Table 1. Due to the increasing number of vehicles the huge traffic congestions occur in urban areas. To avoid delays, road users tend to travel faster without paying attention on road safety rules. According to the report published by Ministry of Transport and Aviation of Sri Lanka, around 40,000 crashes were recorded in Sri Lanka during 2017. The Sri Lanka Police mentioned that, over the decade of 2007–2017, six number of people have died daily in Sri Lanka on average of road traffic crashes. Based on the previous research studies, one of the main reasons for road crashes is the uncontrolled speed limit. Setting and enforcing speed limit is important to reduce the speed at road. When deciding speed limits; road engineers consider the vehicle, roadway, and environmental characteristics.

Table 1: Vehicle Population in Sri Lanka from 2012 to 2017 **(Source: Department of Motor Traffic, Sri Lanka)**

Year	2012	2013	2014	2015	2016	2017
Motor cars	499,714	528,094	566,874	672,502	717,674	756,856
Motor Tricycle	766,784	850,457	929,495	1,059,042	1,116,987	1,139,514
Motor Cycle	2,546,447	2,715,727	2,988,612	3,359,501	3,699,630	4,044,010
Buses	91,623	93,428	97,279	101,419	104,104	107,435
Dual purpose vehicles	280,143	304,746	325,545	365,001	391,888	406,630
Motor Lorries	323,776	329,648	334,769	341,911	349,474	352,275
Land vehicles – Tractors	315,520	326,292	333,362	343,339	353,624	362,275
Land vehicles - Trailers	53,020	55,286	57,298	59,426	63,088	362,446
Total	4,877,027	5,203,678	5,633,234	6,302,141	6,795,469	7,247,122

In Sri Lanka, the national roadways are classified under the class-A, -B, and -E. The maximum speed limit for E-class roadways is 100 km/h and the maximum speed limit of A- and B-class roadways are introduced based on the urban/rural nature and vehicle type. Traditionally, the focus has been made on enforcement to reduce speeding of vehicles. However, on some road sections, enforcement only temporarily reduces operating speeds. Some roads (or road sections) need to be redesigned to more closely match the desired operating speeds. There are many research aimed to study operating speeds, and understanding speed selection. Currently, there is a very little information on setting up the urban speed limits is available in Sri Lanka. Therefore, the objective of this study was to investigate the effect of road, driver, and environmental characteristics on vehicle speed.

2. LITERATURE REVIEW

A research was done to evaluate the applicability of speed limits for Sri Lankan road network and develop a methodology for setting up speed limit for selected road sections (Abeysekara et al. 2012). The scope was limited to straight road sections in flat terrains in sub-urban areas where other characteristics like shoulder conditions, and roadside development were similar. Two A-class roads with similar characteristics and geometry were selected and investigation were done on those road sections. Speed data by vehicle category were collected using radar guns on weekdays ensuring the speed of free flow vehicles with standard headway. The 85 percentile speeds of each vehicle category were estimated comparing them with speed limits. It was found that only three-wheelers and busses exceeded the speed limit and other vehicles managed their speed limits during the selected areas.

Long et al. (2006) evaluated the safety of 1100 km of rural roads in South Australia once speed was reduced from 110 km/h to 100 km/h. Crash data of two years of before and two years of after the speed limit reduction were investigated and found only a 1.9 km/h reduction in the average speed of the vehicles and a 20 percent reduction in casualty crashes. Also, a follow up report on the same roadway segments were analyzed ten years of before and after speed reduction and compared the results with control segments where the speed limit was still 110 km/h. It was revealed that the control segments, which still had the same speed limit, had also experienced a long-term trend of crash counts reduction. However, a pronounced drop in casualty crashes was apparent with speed reduction.

In a similar study, Kockelman (2006) investigated the impact of raising the speed limit on the operating speed as well as the associated variability in the speed on high-speed roadways. It was found that the average speed and the speed variability are more influenced by roadway geometry and cross-sectional characteristics as compared to posted speed limits. These findings were largely reflective of driver opinions on speed limits.

Aljanahi et al. (1999) developed models to investigate trend of crash rates change with regard to various roadway and traffic characteristics including speed. The crash rates were explored on divided highways in two sets of locations, in United Kingdom (UK) and in Bahrain using 200 participants. The data collection was done using automatic speed collectors and vehicle counters. Substantial safety improvement was proposed

that could be achieved either by mandating lower speed limits or reducing the spread of vehicle speeds. Lower crash rates were found in UK sites and there was a strong statistical relationship between crash counts and the variability of traffic speed, while the results for Bahrain were associated with higher crash rates, indicating the mean speed of the traffic is a stronger predictor of crash rates.

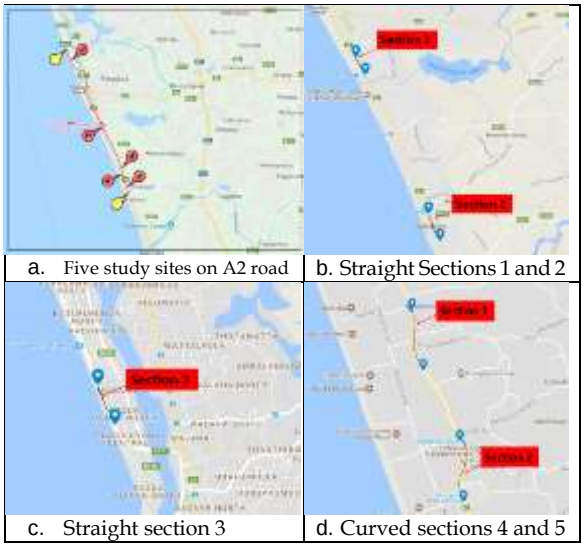
Kurlaftis and Golias (2002) investigated road geometric characteristics and crash rates for the straight rural two lane highway. Width of lane, Average Annual Daily Traffic (AADT), Serviceability Index (SI), pavement type, and friction factor of the tire with the contact area of the road were the investigated sub factors. After summarizing the sub factors, speed was identified as the major influenced factor for increment of crashes. When compared the factors with their relative importance, the relative importance was 100% for AADT, 72% for lane width, 59% for serviceability, 32% for tire friction, and 30% for pavement condition.

Classen et al. (2013) done a study on Older Driver's driving behavior using Geographic Position System (GPS) tracking data in Japan. About 108 older drivers were involved in the data collection process over one month period and examined older driver's behavior on road selection, turning, and speed selection. Drivers filled the basic survey and asked them to install data collection devices in their vehicles. Age limit, peak period, and trip mode were considered in the survey. Through previous studies found that older driver's inclined to drive slowly, this research did not prove that. The older drivers drove faster than other drivers in national and ordinary roads. It was recommended to improve the transportation planning by developing driving assistance systems for older drivers.

Calvi and Bella (2014) investigated speed differential parameters in day and night environments using driving simulator. The main objective was to analyze drivers' speed profiles for evaluation of speed in different conditions. Two lane rural road sections with 10 km length were selected and 40 drivers whose age in between 23 and 41 years were investigated in both day and night conditions. Drivers' speed profiles at the midpoint of the tangent, midpoint of circular curve, maximum speed on last 200m of approach tangent and the speed on the tangent at 100m before the beginning of the curve were recorded. After gathering all the data, the models were developed to find out the correlation between parameters. It was revealed that there was a huge difference in visibility between day and night conditions.

3. METHODOLOGY

Five road sectioned on A2 road between Kalutara and Moratuwa were selected; the length of those section were about 250 m to 350 m as shown in Figure 1. The yellow bullets in Figure 1.a show the boundary of the selected area and the numbered locations give approximate location of selected sections. Those locations were further zoomed-in as shown in Figures 1.b, 1.c, and 1.d. Three straight road sections were selected for the research are shown in Figures 1.b and 1.c. Sections 1 is located in Panudura-Pinwatta area and Section 2 is located Waskaduwa – Mahawaskaduwa area while section 3 is located at Moratuwa New Galle road deviation.



a. Five study sites on A2 road | b. Straight Sections 1 and 2

c. Straight section 3 | d. Curved sections 4 and 5

Figure 1: The Study Area

The street views of all three straight road sections are shown in Figure 2. Two curved road sections selected were Pothupitiya Maha Vidyalaya – Pothupitiya Junction area (section 4) and Pohaddaramulla – Molligoda area (section 5). The street views of two curved road sections are shown in Figure 3.

The AADT is these sections approximately 60,000. Every selected section contains a pedestrian crossing, intersection, and a bus stop. The pavement material in all sections was asphalt and pavement performance was similar.

Section 1	Section 2	Section 3
Panadura – Pinwatta area (From Kalutara Side)	Waskaduwa– Mahawaskaduwa (From Kalutara Side)	Moratuwa New Galle Road Deviation (From Panadura Side)

Figure 2: Street Views of Straight Road Sections

Section 4	Section 5
Pohaddaramulla – Molligoda area (From Kalutara Side)	Waskaduwa– Mahawaskaduwa (From Kalutara Side)

Figure 3: Street Views of Curved Road Sections

The characteristics such as length of section, lane width, number of lanes, vegetation density, and posted speed limits of selected sections are given in Table 2. The distances to the pedestrian crossings and intersections have measured from changing the locations at a time.

Table 2: Roadway Features in Study Sites

Road Section	Length of the section	Lane Width (m)	No of Lanes per direction	Total Lanes	Vegetation Density	Posted Speed Limit of light vehicles
1	350 m	3.0	2	4	Medium	50 km/h
2	275 m	2.8	1	2	High	40 km/h
3	300 m	3.7	2	4	Low	50 km/h
4	275 m	2.7	1	2	High	40 km/h
5	300 m	3.5	1	2	Medium	50 km/h

3.1. Effecting Factors for Speed Selection

After reviewing the past research articles, the factors affecting for the speed selection were selected. Also, some other variables which were unique to these sites found by observation and considered for the study. The human factors are the major causes for every incident happens on the road. The possibility of controlling mind of a person and physical fitness are very difficult. Fatigue, inexperience, and inattention of drivers can be identified as the driver behavioral characteristics which may affect the speed of vehicle. The effect of vehicles factors on speed selection were also considered. A set of factors are considered when designing a vehicle which included the braking and deceleration, acceleration, low-speed turning characteristics, high-speed turning characteristics, size, and weight. Defective brakes, worn tires, and other vehicle defects affect the driving, especially at high speeds. It has been observed that the tire at high speeds and lead to loss of control could be undermined. The separation of the tire tread is another factor that leads to loss of control. Vehicles and traffic interaction, such as surface roughness play an important role in the vehicle stop. The above mentioned factors can be identified as the most common factors for variation of speed. The parameters selected for this study are tabulated in Table 3 and the discussed them in following sections.

Vehicle Type: The main categories of vehicles have defined as passenger cars, buses, trucks, and recreational vehicles. As all the five selected sections are located very close to the urban areas there were several types of vehicles. The gathered 1200 participants were divided into 8 classes by visual observation.

Vehicle Condition: Vehicle condition was recorded after observing its number plate which is assigned based on the sequence of registration in Sri Lanka. The category named 'new' was for the numbers which having two or three English letters at the beginning. And for the 'old' category, the number plates which contains only numbers which have been observed. The condition is directly affected for the speed limit selection due to the performance of the engine.

Table 3: Parameter Definition

No	Variables	Abbre.	Description	Type
1	Vehicle Type	VT	0 Motorcycle 1 Three-wheeler 2 Car 3 Van 4 Cab 5 Bus 6 Lorry 7 Multi-axle vehicle	Categorical variable
2	Vehicle condition	VC	0 Old 1 New	Binary variable
3	Gender	GEN	0 Female 1 Male	Binary variable
4	Driver age (approximately)	AGE	0 18-30 years 1 31-40 years 2 41-50 years 3 51-60 years 4 61 70 years	Categorical variable
5	Number of passengers	PAS	The count of the passengers taken as 1,2,3,4 etc.	Nominal variable
6	Speed	SPD	Observed speed entered as nominal value.	Nominal variable
7	Weather condition	WC	0 Sunny 1 Rainy	Binary variable
8	Time of the day	TIM	0 Morning 1 Afternoon 2 Night	Categorical variable
9	Vegetation density	VEG	0 Low 1 Medium 2 High	Categorical variable
10	Lane width	LW	Entered as the measured length meters	Nominal variable
11	Number of lanes	NOL	Entered as a count	Nominal variable
12	Shoulder width	SW	Entered as the measured length in meters	Nominal variable
13	Posted speed limit	PSL	Entered the speed limit in km/h	Nominal variable
14	Distance to the speed limit sign board	DSS	Entered as the measured length in meters	Nominal variable
15	Distance to the nearest pedestrian crossing from location where measuring the speed.	DPC	Entered as the measured length in meters	Nominal variable
16	Distance to the nearest Intersection from location where measuring the speed.	DI	Entered as the measured length in meters	Nominal variable
17	Day of the week	DOW	0 Weekend 1 Weekday	Binary variable
18	Availability of guard rail at the center of road	AGR	0 No 1 Yes	Binary variable
19	Availability of parking bays	APB	0 No 1 Yes	Binary variable
20	Availability of bus stops	ABS	0 No 1 Yes	Binary variable

Gender: The variable gender was identified by visual observation. The selected sections were close to urban areas and considerable number of female drivers were observed in the study.

Driver age: The new license holders and young generation could not have much experience in driving, most of the time they select middle range of speed. But the middle age drivers tend to drive faster and able to take risks while the older drivers need more reaction time than others. Age of driver was determined by visual observation and divided into five groups as shown in Table 3.

Number of passengers: Number of the passengers in a vehicle were counted when it passes the observer. The passenger count in a bus was approximately entered as it is hard to count while it is running.

Vehicle speed: The spot speeds of

vehicles were measured using the speed guns and recorded in kilometers per hour by vehicle category.

Weather condition: People tend to drive faster in normal weather conditions and mostly decrease their speed in adverse weather conditions. The survey was conducted in both sunny and rainy conditions to check the speed variance in different conditions.

Time of the day: People tend to drive faster in day time and mostly decrease their speed in night due to reduced visibility.

Vegetation density: Due to the vegetation density of roadside, speed of a vehicle can be varied. The vegetation densities have categorized in three groups as low, medium, and high.

Road width: On urban roads, both lane widths were measured from the curb face. Therefore, most carriageways would be the sum of the lane widths.

Number of lanes: The number of lanes was recorded and taken as a nominal value when analysing.

Posted speed limit: The posted speed limit was recorded in km/h.

Distance to speed limit sign: If the posted speed limits have showed on roads, most of the drivers may pay attention for the signs. In this study, the distance from the observing point to the speed limit sign was measured in meters.

Pedestrian crossings: Pedestrian crossings affect the operating speed of the vehicles. Therefore, the distance form pedestrian crossings was measured in meters.

Impact of Intersections: Mean speeds reduce with the traffic density of an intersection. According to the findings of Wang et al. (2006), T-intersections have a similar impact on operating speeds. The distance for the three-way junctions or four-way junctions was measured in meters.

Day of week: During weekends traffic flow is low and high speed on road can be expected. Therefore, data were collected covering both weekends and weekdays.

Availability of guard rails at the center: Previous studies showed the presence of median barrier as a factor to increase the operating speeds. Having guard rail reduces the unnecessary over-takings of the vehicles, as drivers have to move only in their lanes.

Availability of parking bays: Many researchers demonstrated that on-street parking has a statistically significant impact on reducing operating speeds. A road cross-section with parking bays develop a non-clear zone and vehicles pulling in and out of parking spaces have an impact on through traffic and it affects for the operating speed. In this study, some selected areas contain parking bays.

Availability of Bus stops: Bus stop also effects the operating speed of the vehicles.

3.2. Method

The first step of analysis was to develop correlation matrix to identify strongly correlated variables. After excluding highly correlated variables, the multiple regression techniques were used to develop the relationships. Multiple regression is a statistical technique to understand the relationship between one dependent variable and several independent variables. The purpose of multiple regression is to develop a linear equation that can best determine the value of dependent variable Y for different values of independent variables in X. The basic equation of Multiple Regression is:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + \ldots + b_Nx_N \quad (1)$$

The multiple regression model is based on the following assumptions:

- There is a linear relationship between the dependent variables and the independent variables,
- The independent variables are not too highly correlated with each other,
- Observations are selected independently and randomly from the population, and
- Residuals should be normally distributed with a mean of 0 and variance.

R-squared value: The co-efficient of determination, R-squared (R^2), is a statistical metric that is used to measure how much of the variation in outcome can be explained by the variation in the independent variables.

F value: F-test is used to find out whether the variances between the two populations are significantly different.

p value: A small p-value (typically < 0.05) indicates strong evidence against the null hypothesis. A large p-value (> 0.05) indicates weak evidence against the null hypothesis. The p-values very close to the cut-off (0.05) are considered to be marginal.

4. RESULTS

A total of 1,200 vehicles were observed in this study. The observed vehicle composition is shown in Figure 4.

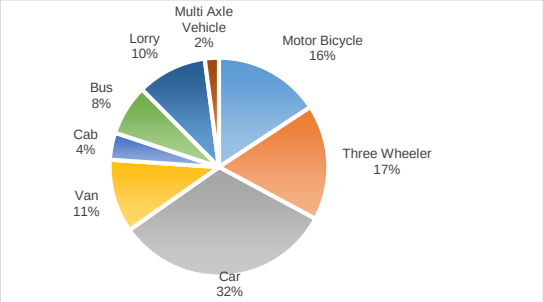


Figure 4: Observed Vehicle Composition

The speeds of observed vehicles were between 18 km/h to 85 km/h. The speed limits of selected sections have shown the common posted speed limits 40 km/h and 50 km/h for every category of vehicles. As shown in Figure 5, the speed versus cumulative percentage curve was drawn considering all the vehicle categories. The estimated 85th percentile speeds for both straight and curved sections were around 65 km/h. Therefore, it can be recommended to increase the posted speed limit up to 65 km/h.

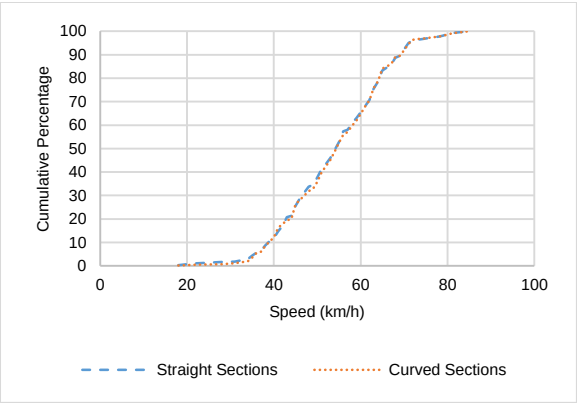


Figure 5: Speed versus Cumulative Percentage Curve

4.1. Multiple Regression Analysis

The correlation coefficient matrixes were developed for both straight sections and curved sections to identify highly correlated variables intending to remove the highly correlated variables in model developments. However, the variables in this study were not highly correlated. Multiple regression analysis models were developed for straight sections and curved sections and given in Table 4. The dependent variable was observed spot speed. The R^2 value which indicates the model fitness is 0.892 for straight sections and 0.914 for curved sections. Therefore, it could be concluded that there is a co-linearity between the results. The independent variables with p-values are lesser than 0.05 ($p < 0.05$) are identified as significant variables with 95% level of accuracy. Vehicle condition, weather condition, lane width, vegetation density, number of lanes, distance the nearest pedestrian crossing, and availability of guard rail affect for the speed variation in straight roadway sections. According to the model developed for curved sections, vehicle type, vehicle condition, weather condition, vegetation density, distance the nearest pedestrian crossing, distance to the nearest intersection, and availability of guard rails, and availability of bus stop affect for the speed variation in curved roadway sections.

5. CONCLUSIONS

The study was conducted by observing 1200 drives in both straight and curved sections. Data collection was done in five sections. From the collected data, it can be identified that most of the vehicles exceeded the posted speed limit. The 85th percentile speed estimated was 65 km/h.

The separate speed models for curved section and straight section were developed. Vehicle type, vehicle condition, weather condition, vegetation density, distance the nearest pedestrian crossing, distance to the nearest intersection, availability of guard rail, and availability of bus stop were considered as the affecting parameters for speed variation on curved roadways. While vehicle condition, weather condition, vegetation density, lane width, number of lanes, distance the nearest pedestrian crossing, and availability of guard rail affect for the speed variation in straight roadway sections.

This study provides the base line to investigate the affecting parameters on speed variations. It is recommended for future research on this topic to be discovered both rural and urban areas covering different classes of roads. The study can be extended for road sections with different geographical features including mountain terrain.

Table 4: Multiple Regression Models

Model	Straight Sections				Curved Sections			
	Unstandardized Coefficients		t	Sig.	Unstandardized Coefficients		t	Sig.
	B	Std. Error			B	Std. Error		
(Constant)	-145.467	170.528	-0.853	0.394	57.574	7.657	7.519	0.000
Vehicle Type	0.291	0.222	1.306	0.192	-0.303*	0.286	-1.060	0.029
Vehicle Condition	-0.024*	1.599	-0.015	0.018	0.528*	1.427	0.370	0.011
Gender	-0.769	1.363	-0.564	0.573	0.604	1.698	0.356	0.722
Age	-0.040	0.044	-0.921	0.358	-0.031	0.056	-0.558	0.577
Number of passengers	-0.386	0.390	-0.990	0.323	0.123	0.488	0.253	0.801
Weather Condition	-7.048*	2.045	-3.447	0.001	-0.036*	0.137	-0.264	0.042
Time of the day	-0.303	0.286	-1.060	0.290	0.28	0.222	1.261	0.168
Vegetation Density	1.207	1.079	1.119	0.024	0.117*	1.594	0.074	0.032
Lane width	0.528*	1.427	0.370	0.011	-0.728	1.363	-0.534	0.593
Number of lanes	2.370	1.565	1.514	0.030	-0.386	0.39	-0.99	0.322
Shoulder width	0.604	1.698	0.356	0.722	-0.046	0.043	-1.066	0.287
Posted speed limit	-0.031	0.056	-0.558	0.577	-10.284	2.404	-4.277	0.139
Distance to nearest ped. crossing	-1.384*	1.131	-1.223	0.022	-6.901*	2.04	-3.382	0.013
Distance to nearest intersection	1.523	1.141	1.335	0.182	3.399*	1.253	2.713	0.007
Distance to the speed limit sign	-0.036	0.137	-0.264	0.092	0.196	0.031	6.338	0.934
Day of the week	0.123	0.488	0.253	0.081	1.165	1.078	1.081	0.428
Availability of guard rail	0.149*	0.286	1.149	0.047	1.546 *	2.191	0.001	0.000
Availability of parking bays	-0.152	0.370	-1.046	0.146	-1.092	4.193	-1.046	0.196
Availability of bus stops	1.467	1.059	-1.051	0.178	4.167 *	1.064	1.493	0.024

*- Significant values at 95% confidence level

Slope and pavement condition were not included this study which could be take into account in future studies.

According to the results, most of the drivers exceed the posted speed limit, hence it is recommended to held workshops and programs to educate the drivers and public about speeding behaviour of drivers. Also, law enforcement could be implemented all over the country.

6. REFERENCES

Abesekara P.T.N., Senanayake M.P.D.S.R.K., Senevirathne S.T.R., Wicramasinghe, and Dissanayake S., 2012, 'Criteria for Setting Speed limits for Sri Lankan Roadways', *Civil Engineering Research Exchange Symposium 2012 Proceedings*, Faculty of Engineering, University of Ruhuna, Galle, March 19, 2012.

Aljanahi, A.A.M., Rhodes, A.H. and Metcalfe, A.V., 1999. 'Speed, speed limits and road traffic accidents under free flow conditions', *Accident Analysis & Prevention*, 31(1-2), 161-168.

Calvi, A. and Bella, F., 2014. 'Modeling speed differential parameters in day and night environments using driving simulator', *Procedia Engineering*, 84, 648-661.

Classen, S., Wang, Y., Crizzle, A.M., Winter, S.M. and Lanford, D.N., 2013. 'Predicting older driver on-road performance by means of the useful field of view and trail making test part B', *American Journal of Occupational Therapy*, 67(5), 574-582.

Long, A. D., Kloeden, C. N., Hutchinson, T. P., & McLean, A. J. 2006, 'Reduction of speed limit from 110km/h to 100km/h on certain roads in South Australia: A preliminary evaluation', *2006 Australasian Road Safety Research, Policing and Education Conference,* Gold Coast, Australia, 25-27 October 2006.

Kockelman, K.M. and Ma J. 2007. 'Freeway speed and speed variations preceding crashes, within and across lanes', *Journal of Transportation Research Forum* 46(1), 43-61.

Wang, J., Dixon, K.K., Li, H. and Hunter, M., 2006. 'Operating-speed model for low-speed urban tangent streets based on in-vehicle global positioning system data', *Transportation research record*, 1961(1), 24-33.